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The nutritive and economic potential of cowpea (Vigna unguiculata and lablab (Lablab purpureus) legume hay as supplements to sun-cured corn (Zea mays indentata) stover

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" The desire of knowledge, like the thirst of riches,
increases ever with the acquisition of it."

Sterne

This dissertation is dedicated with the greatest love and gratitude to my parents and departed aunt of Monrovia, Liberia.

To

Mrs. Sally Tonpo Johns
Mr. Gorgori Johns
Aunt Payda Tonpo

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INTRODUCTION

Some common effects of nutrient imbalance on ruminants are reduced feed utilization, slow growth rate, and prolonged parturition interval. Inadequate fermentable N, protein, energy, minerals, and other microbial growth precursors, are the most limiting nutritional factors that affect ruminant livestock in Sub-Saharan Africa (SSA).

Crop residues are abundant, and are the feedstuffs used by most livestock farmers during the dry season in SSA. However, the residues are fibrous, low in N and essential minerals. Seasonal fluctuation in feed quality and supply also makes it difficult for livestock to meet their nutritional requirements, especially during the long dry season. Consequently, feed utilization is low, and animals fed crop residues often exhibit poor performance.

Methods to improve the nutritive value of these feeds are: 1) alteration of the fibrous components through chemical, physical and/or biological treatments; 2), addition of nutrients which provide an optimal rumen environment in which digestion of structural carbohydrates is increased.

Research has shown positive results from animals fed chemically or physically treated fibrous feeds. However, complexities of methods, cost and unavailability of processing materials, make these technologies difficult to be adopted by small farmers. This leaves most livestock producers who do not have the financial means and technical know-how with little incentive to upgrade their existing feeding

practices. Additionally, others with capital are skeptical about taking the financial risk of replacing existing practice with new methods. A common reason, is that most of the new methods are not backed by an information package describing their comparative economic advantages relative to existing practices.

These conditions have created two major challenges for livestock research scientists in SSA. First, they need to develop a cost effective and strategic supplementation program with the objective of enhancing the utilization of available feedstuffs. Secondly, they need to develop a simple and adaptable livestock production system whose biological and practical effects on growth rate, reproduction, and draft power could be measured in economic terms, as compared with existing practices.

Supplementation of low quality crop residues with locally grown forage legumes could create an efficient rumen ecosystem and increase rumen microbial biomass production. Such a strategy would enhance utilization of these fibrous crop residues, and thereby, wil improve the productivity of those livestock that subsist primarily on low quality roughage.

Feeding systems that incorporate low quality roughage with forage legumes have shown positive results in growth rates (Sundstol and Owens, 1984) and increased ruminal fluid volatile fatty acid concentrations of cattle (Saduliah et. al., 1983). Adequate amounts of essential minerals (Kabaija and Little, 1987) and rumen degradable organic matter (Yilala, 1987) have also been observed. Research conducted at the Debre Zeit Research Station, International Livestock

Center for Africa, Ethiopia where teff straw was supplemented with various levels of cowpea or lablab, and fed to calves, indicated some improvement in growth rate. Some positive associative effects have been observed in feed intake with lambs, when cowpea or lablab was combined with blood meal as a supplement to corn stover. An increase of 13% in DM digestibility, and 10% in N retention was reported (Smith et al., 1988) in sheep fed a basal diet of corn stover supplemented with cowpea.

In spite of the above reports, there is limited information available on the characteristics of these feedstuffs, and their effects on nutrient digestion and metabolism and digestion in the rumen when fed as a supplement to low quality roughage. The optimal ratio and/or level of supplementation which enhances the utilization of the basal feeds, and maximizes returns or income, is another area which has received little attention, especially for locally grown forages in SSA.

Management and feeding systems have a major influence on the growth and reproductive efficiency of animals. Therefore, final body weight is often used by livestock producers to determine the market worth of their animals at the end of a production cycle. For most farmers in SSA, the acceptance of a new agricultural technology is initially based on whether it is profitable, socially acceptable, and simple.

Simple economic parameters such as the value of animals before and after supplementation, basal feed, supplements, and labor are essential data which could be gathered, and analyzed during the process of evaluating new feed

resources. Comparisons to ascertain whether it is profitable to supplement, using output (income, meat, manure, milk, draft, etc.), as economic indices are also essential for assessing the acceptability and potential economic impact of a new feeding system. In some instances, where more than one feed is available, some farmers are also interested in knowing the optimal level of feeding or supplementation which maximizes the final output.

Therefore, this research was designed to enhance the general project title: " ***The nutritive and economic potential of various sources of nitrogen supplements on the utilization of poor quality roughage by small ruminants in Sub-Saharan Africa***". The poor quality roughage used was sun-cured corn stover (*Zea mays indentata)*, whereas cowpea *(Vigna unguiculata)* and lablab (*Lablab purpureus)* hays were used as supplements.

General Objectives

1. To determine the chemical composition, degradation, and passage kinetics of cowpea (CWP), lablab (LAB), and sun-cured corn stover (CS).
2. To determine the effects of supplementing CS with CWP and/or LAB when fed in combinations or graded levels on intake and digestibility of dry matter (DM), neutral detergent fiber (NDF), nitrogen (N), and gross energy (GE).
3. To determine the effects of supplementing CS with CWP and/or LAB fed in combination and graded levels on nutrient metabolism using ruminal fluid pH, ammonia nitrogen (NH_3-N), volatile fatty acid (VFA) concentrations,

N retention, and microbial N supply as indices of efficient digestion.

4. To determine the effects of supplementing CS with graded levels of CWP on the growth performance of Ethiopian Menz lambs.
5. To determine the economics of CWP supplementation using cost of production, total DM intake, average daily gain (ADG), feed conversion efficiency (FCE), and substitution rate for CS as economic indices .

CHAPTER I. GENERAL LITERATURE REVIEW

A. The Utilization of Forages by Ruminant Animals

Ruminant animals have the ability to convert plant materials to products that are useful to humans. This has been the basis of the emphasis placed on the use of ruminant animals in the early stages of agricultural development. Polysaccharides found in stems, leaves, and roots of feeds are digested to provide energy for the ruminant animal and rumen microorganisms. Demeyer (1981) observed that plant tissues entering the rumen are colonized within 5 minutes by bacteria, within 15 minutes by protozoa, and within 2 hours by fungal sporangia and rhizoid. Unlike nonruminants, ruminants are foregut fermenters, thus they depend on the activity of the rumen microbes to supply most of the nutrients needed for the various physiological functions.

However, the efficiency with which forages are utilized by ruminants depends primarily on the physical nature of the feed, its chemical composition, balance, and availability of nutrients. Other animal factors include the previous nutritional history of the animal, its physiological state, rate of feed intake, rate of digestion, and rate of passage as influenced by the rumen environment.

The quality of the forage and its ability to provide nutrients to support the rumen microorganisms will consequently determine the type of microbial population, efficiency of fermentation, and rate of production and removal of endproducts. Deficiency in any of the nutrients required by rumen microorganisms

may reduce microbial growth, and consequently DM digestion, and overall feed intake, particularly for feeds that are fibrous.

Similarly, the thermal environment, previous nutritional history, and physiological state of the animal determine quantitatively the nutrient demand, and may also alter the utilization of nutrients needed for anabolic functions. Interactions which occur among these factors when feed is presented to the animal and ingested determine the degree with which the material is utilized.

In temperate regions, forages fed to ruminants are generally of higher quality, and where certain nutrients are deficient, they are supplied as supplements. Contrarily, in tropical and subtropical countries, ruminant animal production for most of the year is based on the use of low quality forages and crop residues usually without adequate supplementation. Leng (1990) and Jackson (1981) defined low quality forages as cereal based straws and stover, cut or standing grass hay that are fibrous, low in crude protein, soluble sugars and essential minerals, and have digestibility that is less than 50%.

One of the major priorities for ruminant production based on forages is to ensure that there is no deficiency in the diet of critical nutrients, which are required to optimize the activity of rumen microbes. Carbohydrates, nitrogenous compounds, branched chain VFA, and minerals are essential for enhancing the rumen environment, and consequently, the growth of the rumen microbes. However, the availability of these critical nutrients may be limited by nutritional and/or animal factors.

B. Factors that Limit the Utilization of Forages by Ruminants

1. Nutritional factors

a. Physical nature of the forage

Stage of maturity The nutritive value and utilization of forages are influenced by the stage of growth at which the plant was grazed or harvested. Forages grazed as standing hay, cut and fed fresh or dried are all affected by the stage of maturity. Generally as a plant matures, proportion of stem increases from about 28% to 60% and structural carbohydrates increase up to 45% of the dry weight (Mangan, 1982). Crude protein decreases from 19% to 10% for most high quality forages (Ulyatt, 1981).

The influence of stage of maturity on nutrient composition is more pronounced with forages of cereal origin, such as straws and stover, especially those grown in tropical environments. Egan (1984) explained that the nutritive value of tropical forages decreases with increased maturity because of the increased amount of protein that becomes associated with the cell wall. This reduces the quantity of protein available either to the rumen microbes or to the host animal. Santana et al. (1989) studied the nutritive value of LAB in relation to its growth stage in wethers and observed that digestibility of DM and crude fiber were higher at the flowering stage, whereas organic matter digestibility, crude protein and dry mater intake were greater at the milk stage.

Extensin appears to contain about 90% carbohydrate and only 5% protein (Mangan, 1982), and its strong linkage with cellulose suggested that rate of rumen

degradation of this cell wall bound protein would be lower. Translocation of leaf protein to seed protein with increased maturity and differences in protein contents between parts of plants (Loneragram, 1973) are some reasons for the reduced nutritive value of forages with increased maturity.

Unlike temperate forages, which may contain more soluble protein, about 20% of the protein in tropical forages is present in the vascular sheath, which is resistant to microbial degradation (Egan, 1984). The overall effects of maturity are disproportionate increases in the fiber components and a consequent reduction in voluntary intake, dry matter digestibility, and availability of nutrients (Minson, 1982).

b. Processing method

Numerous methods are used to conserve forage to maintain or improve its nutritive value for some period before feeding. Physical treatment consists of chopping, grinding, pelleting, and air or artificial drying. Sodium hydroxide, anhydrous ammonia, urea, and other alkali are used for chemical treatment of forage. Ensiling has also been used in temperate regions as another means of conservation, especially for high quality forages. The goals of the various processing methods are to reduce particle size and bulkiness, lower moisture content, and break the fiber matrix of the feed before feeding.

Physical treatment Sun-curing and artificial drying are methods used to conserve forages in addition to ensiling. The effects of these methods depend on the feedstuffs, which vary among forage species, variety, and stage of maturity at harvest. Natural drying is a common practice in the tropics where the long dry

season makes it conducive to sun-cured forages. Artificial drying may be carried out under varying temperature conditions, but commonly the product is ground, pelleted, and/or packaged as part of the processing method.

Nutritionally, the effect of drying is an increase in DM, but Blaygoveshensky et al. (1978); Sutton and Vetter (1971) reported a marked decrease in protein after drying. McDonald (1982) reported that during drying the plant continued to respire. and suggested that the increased respiration leads to the oxidation of sugars, organic acids, and an increase in proteolysis. Plant enzymes (Clark, 1974), presence of oxygen, and higher pH (Ohyama, 1970) have been suggested to be responsible for the increase in proteolysis. The presence of various carbohydrates (Bjarnason and Carpenter, 1970) has also been implicated as one of the causes of the rapid proteolysis of leaf protein during heat treatment.

These effects have been observed in plants and leaves that are dried at ambient temperature for over 24 hours, and for mechanical drying at high exit temperature. Marsh (1976) observed that exit temperatures of 77° C to 119° C have minimal effects on *in vivo* protein digestibility, but exit temperature in the range of 145° C to 166° C severely reduced the availability of leaf protein.

Another effect of heat treatment on protein availability is the formation of new cross linkages within and between peptide chains. Valley-Riestra and Barnes (1970) suggested that enzyme resistant cross linkages may be formed through reactions involving protein side chains and products of advanced Milliard reactions. Internal formation of amides or esters and loss of polar groups make the cross

linkages resistant to gut protein hydrolysis (Ford, 1975).

Correspondingly, ensiling involves partial wilting of herbage in the field, collection, and ensiling with or without additives. Rate and process of fermentation in addition to plant and microbial enzymes are the main factors that influence the nutritional characteristics of silage. Lactic acid in silage is considered to be non-proteolytic, but McDonald (1976) and Hughes (1970) reported that during ensiling, asparagine and glutamine are catabolized resulting in the production of ammonia. Fermentation of amino acids by *Clostridia and Enterobacteriaceae* to form butyrate as an endproduct, and secretion of protease (Deacon 1980; Mead 1971) also occurr during ensiling of forage. Addition of lactic acid producing bacteria and other chemicals such as formic acid and formaldehyde have been suggested (Carpenterio et al., 1979; Kreula and Ravramaa, 1977) to decrease the proteolytic activity of plant and bacterial enzymes.

Other physical treatments such as pelleting, chopping, and grinding could also increase the utilization of poor quality roughage. Grinding and pelleting are often used after either drying or pretreatment. Chopping of forages such as CS has been shown to increase total dry matter intake due to reduction in selection and wastage (Xang, 1988). Roughages that are threshed mechanically have been reported by Hammersen et al. (1984) to be better utilized because fractured cells provide a better surface area for microbial attachment and degradation.

Chemical treatment Most forages of cereal origin are low quality and this often results in low utilization. Considerable interest has been directed toward

improving the intake of these roughage through chemical treatment. The general objective of chemical treatment of low quality roughages is to loosen the fiber matrix and expose them to enzyme and bacterial degradation. It is a well established fact that chemical treatment can improve the feeding value of low quality forages by increasing the digestibility of energy and/or by increasing feed intake (Jackson, 1981).

Several attempts have been made to improve the utilization of low quality roughage by using various chemicals (Sundstol and Owens 1984; Jackson, 1977). The most successful chemicals have been sodium hydroxide (NaOH), ammonia, and urea. Levels of 3% to 6% NaOH are considered optimum, but at a level above 6% *in vivo* digestibility and voluntary intake reached a maximum and may sometimes decline (Jackson, 1977). Chopped barley straw treated with 4% NaOH and fed to dairy cows resulted in increased milk yield and fat content of milk compared with untreated straws (Kristensen et al., 1984). Greenhalgh et al. (1976) fed barley straw treated with 6% NaOH to dairy cattle and observed daily DM intake to increase from 10.8 to 13.4 kg and milk yield from 17.6 to 19.0 kg per day.

Feeding ammonia treated straw has also been shown to increase milk yield and milk fat content in cows (Kristensen et al., 1984). Digestibility of cell walls increased from 50 to 71 and 69% in sheep and cows, respectively, fed 3% ammonia treated barley straws (Cottyn et al 1989).

Deficiency of magnesium (Mg), lower rumen retention time, and reduced utilization of N have been observed from alkali treatment of low quality roughage.

Hvelplund (1989) reported low N utilization and high fecal N excretion from sheep fed ammonia treated straws. Magnesium and phosphorus deficiency (Andersen et al., 1989) and increased rate of passage of potentially digestible feed from the rumen of sheep (Berger et al., 1980; Combe et al., 1979 and Oji et al., 1979) have also been observed for NaOH and ammonia treated straws, respectively.

Increased proportion of organic matter in alkali solubilized straws and increased water consumption after intake of NaOH treated materials could, in part, explain the decreased rumen retention time of feed particles. Proportion of treated materials in the diet could also affect the utilization of alkali treated materials. Kristensen et al. (1977) reported that feeding a low proportion of treated materials, and a high proportion of easily fermentable carbohydrates, resulted in a complete absence of an improvement in digestibility of alkali treated as compared to untreated materials. The general benefit from alkali treatment of fibrous roughage is that it removes the phenolic acid residues in the fiber that acts as a barrier to microbial degradation.

c. Chemical composition

Chemical composition is a primary indication of the capacity of a feed to meet the nutritional requirements of the animal. Through laboratory analysis, the concentrations of available and unavailable components, organic structures, and inhibitors are determined. Chemical analysis is used to characterize feeds, but does not give a direct estimate of their nutrient potential. Generally, the nutrient potential of a feed is dependant on interactions among both feed and animal

factors. Therefore, it is difficult to find a parameter which will adequately estimate nutritive value over a wide range of feedstuffs (van Soest, 1987).

For forages, the fiber components (cell wall, cellulose, hemicellulose, and lignin), protein, energy, and minerals are parameters that are used to estimate the nutritional potential of feeds. The fiber components of feeds are the polysaccharides consisting of cellulose, hemicellulose, and pectin. Other components are some proteins and small quantities of fat, silica, salts, and lignin.

Fiber components, especially lignin and NDF, are the criteria used most often to categorize forages as low and high quality feed. Forages with high fiber content usually have lower digestibility when fed without supplementation. van Soest (1987) reported a correlation of -.90 between the fiber content and overall digestibility from a study of 187 forages of diverse species.

Cellulose is a glucose polymer with no substitute groups, whereas, hemicellulose which accounts for about 30% to 40% of the carbohydrates are complex polymers such as oxylose and arabinose substituent groups. Pectins are polygalacturonic acid with methyl and other substituent groups. The amount of organic acids, silica, salts, and lignin found in forages varies with maturity of the plant, being greatest in older vegetation. The rate of degradation of plant fiber depends on the stage of maturity and the types of microbes present in the rumen (Hobson and Wallace, 1982).

Distension of the recticulo-rumen limits the intake of high fiber diets. Baile and Forbes (1977) reported that after the ingestion of a high fibrous diet by ruminants,

the retecticolo-rumen was distended and intake was curtailed before the nutrient requirement of the animal was met. Grovum (1977) mentioned the relative importance and existence of satiety control receptors in the rumen reticulum and they are activated upon distension when a high fiber diet is consumed.

The influence of fiber content on the utilization of forages is also related to the rate of passage through the rumen. Ground or finely chopped forage has a higher rate of passage, and therefore a higher intake, which may cause a reduction in the extent of digestion. Some positive effects of fiber on the nutrition of ruminants from forages are its role in providing acetate for lactating cattle and as a stimulant for salivation.

The roles of protein, energy and minerals are to supply nutrients for the microbes to enhance the digestion of the feed. The VFA, which are the endproducts of fermentation and digestion, are major sources of energy for the host animal to carry out its physiological functions. The effects of protein, energy, and minerals are manifested when there is a deficiency or imbalance.

Common symptoms of energy and protein deficiencies are reduced feed intake, slow growth, lower milk yield, and sometimes death. Toxicity with protein or energy has not been clearly shown, except when rumen ammonia reaches a toxic level (Bartley et al., 1981). An increased deposition in adipose tissues could be considered as excess energy consumption. Deficiency and toxicity are found with minerals, but such conditions come about as a result of interactions between respective minerals, underfeeding, and overfeeding.

Antinutritional substances The presence of "antinutritional substances" in the forage affects their utilization. Antinutritional substances are found in forages and may impact resistance to biological degradation and sometimes produce toxic substances that can be fatal to the animal. Some classes of these substances are: phenylpropanoid, terpene, alkaloids, and cyanogenic glucoside. There is a wide range in the mode of action of these substances on the animal. Some may act as inhibitors of enzyme activity, while others may interfere with metabolism. Others like tannin are unspecific, but may precipitate and inactivate proteins. However, condensed tannins at low levels such as in legumes may decrease ruminal N loss and increase intestinal amino acid absorption (Barry and Blaney 1987).

Phenylpropanoids interfere directly with animal metabolism and inhibit bacterial activity in the rumen, whereas the isoflavanoid sometimes has an estrogenic effect on the animal. Terpenes include the essential oils, saponin, steroid, and latex. These produce substances that are toxic to animals and they also inhibit microbial activity. Saponins are plentiful in forages and are among the major causes of bloat, especially when animals are grazed or fed a large quantity of fresh forage. The cyanogenic glycosides contain hydrocyanide which is highly toxic to animals.

Analytical procedures for determining the amount of antinutritional substances such as phenolic polymers in the feed have not been standardized, despite their known adverse effects on feed utilization (ARC, 1987). Estimation of total phenolic compounds by using acetyl bromide as described by Morrison (1972) could be useful, but interference by condensed tannins has been reported (Carre and

Brillouet, 1986) to be a problem. The rumen contains microbes which can function as detoxifying agents, and their action minimizes the problem of toxicity with mixtures of plant species.

d. Associative effects

Rations for ruminants are often prepared from a mixture of different types of feedstuffs. Associative effects sometimes occur either as a decrease or increase in feed utilization. Ferrell (1988) defined associative effects as the influence one feed has on the other when fed in combination. Utilization of a poor quality feed may be enhanced by feeding it in mixture with other feeds of higher quality. Ferrell (1988) stated that the alleviation of nutrient deficiency could improve the utilization of poor quality feed.

Associative effects as a result of interactions between feeds was first studied by some German workers at the end of the 19th century. This was followed by the work of Forbes et al. (1931) and Blaxter (1962) who observed associative effects for net energy and apparent digestibility of mixtures of feeds. Other scientists (Silva and Orskov, 1984; Byers et al., 1976) reported both positive and negative effects from various studies with cattle and sheep.

Level of feeding below or above maintenance influences the nonadditivity effects observed with feed mixtures. Joaning et al. (1981) fed a mixed corn silage and corn grain diet at a level of twice maintenance and observed a 11% decrease in DM digestibility, a depression of 57%, 32%, and 12% in starch, NDF, and protein utilization, respectively. Sofi et al. (1982) reported positive associative

effects on both feed intake and digestibility when poor quality soybean stover and high quality alfalfa forages were blended and fed to sheep. Patterson et al. (1982) also reported positive associative effects on digestibility when alfalfa was added to a NaOH-treated corn cobs, and explained that a decrease in rate of passage may have increased the ruminal degradation of corn cobs.

Several attempts have been made to explain the phenomena of associative effects between feeds. A depression in rumen pH with feeding of rapidly degradable carbohydrates that caused a reduction in the number of cellulolytic bacteria has been reported (Stewart, 1977; Mann and Orskov, 1975). Preferential change of certain strains of cellulolytic bacteria (*Butyrivibrio sp*) to utilization of simple sugars rather than degraded cellulose has also been proposed (van Glyswych and Labuschangne, 1977). Others (El-shazly et al., 1961) suggested competition between cellulolytic and amylolytic bacteria as a primary reason for the inhibition of cellulolysis when starch was added to a high fibrous diet. Generally, the types of associative effects that occurr when a mixture of feeds is fed is dependant on the interaction among feeds and among microbes in the rumen.

2. Animal factors

Past nutritional history of animals, rate of fed intake, and rate of passage through the gastro-intestinal tract have some influence on the utilization of a forage based diet. These factors affect the rumen environment and the efficiency of rumen microbes to transform dietary constituents to support the physiological and

biochemical functions of the animal.

a. Previous nutritional history

Previous nutritional history is important because it is an indicator that is used to determine the level of feeding or supplementation that is required to achieve the desired performance, especially for animals that have been under a low plane of nutrition. Age of the animal at which the restriction was imposed and the severity and duration of inadequate nutrition dictate the consequences of realimentation.

Cattle and sheep restricted at early ages show no response in growth after realimentation (Tudor and O,Rourke, 1980; Everitt and Jury, 1977). Similarly, animals reared almost to maturity on a good plane of nutrition have shown no response in performance when a higher nutritional regimen was imposed (Stuedemann et al. 1968; Wardrop, 1966). Other researchers (Wanyoike and Holmes, 1981; Graham and Searle, 1975) reported improvement in growth rate after realimenetation. Ryan (1989) suggested that if the restriction is longer and severe enough to cause a reduction in the size and activity of the digestive tract and liver, the time required for animals to compensate is much longer. Change in chemical composition of gain (Black, 1983) and rate of protein deposition in the digestive tract leading to an increase of nitrogen retention (Hovell et al., 1987) are some physiological influences that determine the response to realimentation. Increased feed intake and efficiency of energy deposition have also been reported by Gingins et al. (1980).

b. Feed intake and rate of passage

Ingestion of feed and the rate at which it is digested in the recticulo-rumen and lower tract are the result of its rate of passage. The amount of feed digested in the rumen is a balance between the inherent digestion rate and the rate of passage of undigested feeds from the rumen (Waldo, et al., 1972). Voluntary intake and extent of digestion of fibrous components of forages varying in quality are functions of the rate of passage of particulate matter from the rumen (Ulyatt et al., 1984). Similarly, the retention time of protein supplements in the rumen is related to the degradation of the protein by the rumen microbes (Stern and Satter, 1982).

Rates of passage of particulate matter and liquid are influenced by such factors as rumen volume, rate of intake, and particle size in relationship to its breakdown. Rumen volume and rate of intake are related to the composition of the diet and particle size as influenced by the rate of breakdown in the rumen. Therefore, passage rate is a function of intake because increased intake of feed increased the outflow of undigested matter (Balch and Crampling, 1965).

The outflow of liquid and particulate matter represents two different pools and is influenced by separate factors (van Soest, 1987). Animal species differences relative to the rate of passage of particulate matter and liquid, the former being slower in large and small ruminants was also reported by van Soest (1987). Type of cell wall constituents of feeds consumed by nonruminats and ruminat are major possibilities for causing the differences reported. The slower rate of passage of particulate matter could be related to the various stages of rumination

(regurgitation, reinsalivation, remastication, and reswallowing), which are prerequisite processes before digesta is moved to the lower tract. Colucci et al. (1982) reported that ruminal fluid dilution rate is slower for concentrates than for roughages, whereas, dilution rate of solids is greater with concentrates than forages because of the reduction in the degree of stratification and saliva flow to the rumen.

Inert liquids and solids are the most common materials used to quantify the differential rates of passage in the rumen and the lower tract and their relationships to feed intake, rate of fermentation, and the overall feed digestibility (Uden et al., 1980; Grovum and Williams, 1977). Estimation of the kinetics of digestion with markers using available models is based on the assumption that there is a steady state condition in the rumen (Robinson et al. 1987).

Interactions among the various factors make it difficult to define a simple cause and effect relationship between residence time and feed intake. Specific gravity, wettability, degree of stratification, and particle size are factors that have been reported (Welch, 1986; Poppi et al., 1980) to influence feed intake and rate of passage.

3. Rumen microbial factors

a. Rumen environment

Rumen microorganism The affinity of microbes for specific nutrients has been the basis of manipulating the rumen ecosystem through supplementation.

The amount of feed organic matter digested in the rumen and the efficiency with which these are used by the microbes for growth determines the output of microbial organic matter and the products of fermentation (Owens and Goetsch, 1988). Similarly, the composition of the microbial population at a specific time in the rumen is therefore, the function of the substrates, the environment created by the substrates, the interaction between microbes, and competition among them for preformed or supplied nutrients of dietary origin (van Soest, 1987).

Organisms with the enzymatic capability to utilize a substrate will dominate (van Soest, 1987). A roughage diet that is high in cellulose, with minimal soluble sugar, but low in starch, stimulates the proliferation of cellulolytic and to a limited extent sachrolytic bacteria. On the contrary, a diet low in fiber and high in starch increases the activity of amylolytic microbes, at lower pH, resulting in an increase in propionic acid production.

The rumen ecosystem is complex and its fermentative characteristics are influenced by the microbial species and the interaction between them. Density of the microbial population in the rumen at a specific time is regulated by a dynamic ecological process. There is a continuous reflux of water, feed particles, some gases that are trapped in the feed, and the production and removal of endproducts of fermentation. Rumen microorganisms are obligate anaerobes, but are able to tolerate some oxygen as long as fermentation rate is high enough to facilitate the disposal of oxygen and maintain the redox potential within the range of Eh -250 to -450 mv (van Soest 1987).

Major cellulolytic bacteria found in ruminants that subsist primarily on fibrous feeds are *Fibrobacter succinogenes, Ruminococcus flavefaciens and Ruminicoccus albus*. One of the major roles of *F. succinogenes and R. flavafaciens* is to synthesize the most active cellulase and hemicellulase of plant cell walls (Hobson and Wallace, 1982). *Prevetella ruminicola and Butyrivibrio fibrosolvens* are noncellulolytic bacteria, but they are capable of producing some hemicellulase. Coen and Dehority (1970) explained that their main function is to remove the inhibitory hydrolytic degradation products, thereby increasing the hydrolysis and degradation of the hemicellulose component.

Other microbes that are involved in cellulose digestion are some species of entodiniomorphs. Strains of *Neocalimastix frontalis* fungi are also known to ferment the plant cell wall as a source of carbon and energy (Orpin and Letcher, 1984).

Interactions between microbes Synergistic and interspecies hydrogen transfer are major interactions that occur between rumen microbes to enhance the degradation of plant cell walls. There are many nonfibrolytic microbes in the rumen of animals that are associated with feed particles. Van Glyswyk and Schwartz (1984) reported that these nonfibrolytic microbes have the ability to hydrolyze non-structural carbohydrates and ferment cellulase product. Gradel and Dehority (1972) observed synergistic actions between pectin hydrolyzing and pectin utilizing bacteria. Combinations of strains of *Ruminococcus flavefaciens and P. ruminicola* resulted in an increase in degradation and utilization of pectin in alfalfa from 30% to 82%. Interspecies hydrogen transfer by methanogenic bacteria to reduce partial

pressure of hydrogen in the rumen and disposal of hydrogen by reduction of fumarate to succinate, sulphate to sulphide, and nitrate to nitrite have been reported among several species of rumen microorganisms (Erfle and Mahadevan, 1986; Demeyer and Vervaeke, 1985).

b. Regulators of microbial growth

Rumen pH Rumen pH appears to have a major impact as one of the constraints that may be responsible for the inhibition of cellulolytic microbes activity and reduced fiber digestion (Hoover, 1986; Mould and Orskov, 1984). In order to maintain activities of cellulolytic microbes, the rumen environment must have a pH range of 6.2 to 7.0. A rumen pH less than 6.2 will seriously inhibit growth of most microbial species with the exception of *S. bovis* (Stewart, 1977).

The effects of rumen pH on fiber digestion occurs in two phases. A reduction in rumen pH from 6.8 to 6.0, will result in a moderate reduction in fiber digestion (van der Linden et al., 1984) whereas a decrease in pH to below 6.0 causes severe inhibition of cellulolytic activity (Mould and Orskov, 1984). The reason for moderate reduction in fiber digestion at a pH range of 6.8 to 6.0 has not been well explained, but it is suggested (Cheng et al., 1984; Smith et al., 1973) to be due to the inability of microbes to remain attached to feed particles because of the washout of bacteria at lower pH. Shriver et al. (1986) conducted a study in continuous culture with mixed concentrates and forages at various pH levels, and observed that at pH 5.8, the number of fibrolytic microbes was reduced by 43%, as compared to only 15% at a pH range of 6.2 to 7.0. Neutral detergent fiber digestibility at pH 5.8 was

8.1% compared with an average of 32.5% at a pH range 6.0 to 7.0.

When a roughage diet is fed, through the processes of mastication and rumination, the contractile activity of the rumen and the flow of saliva are increased. The copious saliva produced contains sodium, bicarbonate, potassium, phosphate, and carbon dioxide. Bicarbonate and phosphate are the major anions. They have pK values of 6.2 and 7.4 respectively, and therefore serve as buffers, to maintain rumen pH above 6.0 for cellulose digestion (Orskov and Ryle, 1990). Kay (1966) estimated that sheep fed a roughage diet produce about 6-12 liters of saliva per day.

Nitrogenous compounds A deficiency of ruminal ammonia may limit the growth of rumen microorganisms with diets based on crop residues or low quality roughages with low N content. Ammonia is supplied from feed N and endogenous N recycling into the digestive tract. Demeyer (1981) reported that about 20% of the nitrogen used by rumen microbes comes from ammonia, but this value varies with the protein content of the feed. Some of the bacteria that are attached to large feed particles incorporate a large proportion of their N from amino acids or amino peptides (Owens et al., 1984).

The level of NH_3-N that will support optimal microbial growth in the rumen varies among diets, and concentrations recommended by researchers are very controversial. For most forages, Satter and Slyter (1974) suggested 50-80 mg NH_3-N/l of rumen fluid was adequate, while Perdock et al. (1988) and Kreb and Leng (1984) indicated 200 mg NH_3-N/l was needed for optimum voluntary intake of low

N and high fiber forages by ruminants. The different values reported by various authors could be partially due to the different requirements of NH_3-N for optimal microbial yield as compared to that needed for better digestion (Mehrez et al., 1977).

Decreased feed intake and utilization has been reported (Preston and Leng, 1987) as the major effect of lower NH_3-N concentrations in the rumen. Owens and Goetsch (1988) explained that reduced feed utilization could be the result of the use of inefficient pathways for ammonia fixation and adenosine triphosphate (ATP) uncoupiing. Glutamine synthetase (GS), and glutamate dehydrogenase (GDH) are two major enzymes used by rumen bacteria to fix NH_3-N to carbon. Glutamine synthetase has a high affinity for NH_3-N, therefore, at low rumen ammonia concentrations it is used more extensively than is GDH (Owens and Zinn, 1988). For each mole of NH_3-N fixed, GS required one mole of ATP, whereas no ATP is needed if GDH is used under conditions of adequate ammonia concentrations.

A condition of ATP uncoupling occurrs when ammonia concentrations in the rumen is low. During the process of ATP uncoupling, fermentation continues, but the endproducts are not used for biosynthesis, but instead for polysaccharide storage or the generation of heat for the survival of the microbes. More than one third of the ATP yield from glucose was reported by Owens and Zinn, (1988) to be used for storage of glucose as polysaccharide through normal metabolic pathways. Overall feed intake and digestibility declined because of either the starvation of rumen bacteria for ammonia or the diversion of ATP from growth to ammonia

uptake.

There is no conclusive recommendation in the literature on the concentration of rumen NH_3-N that is adequate for enhancing the digestibility of various feedstuffs. The different values reported by various authors could partially be explained from suggestions of Orskov (1988) based on studies of Mehrez et al. (1977) and Wallace (1979) which states that; 1) the concentration required for maximal microbial yield is not equal to the concentration required for optimal rate of digestion, and 2) most substrates required different concentrations of ammonia to give an optimal microbial yield. Czerkawski (1978) hypothesized that large feed particles require a higher concentration of ammonia to sustain maximal growth of the bacteria attached to them. Madsen and Hvelplund (1985) confirmed that there are micro environments created by differences in the size of feed particles. Harrison and McAllan (1980) also suggested that variation in cell populations and permeability had made it improbable that one concentration of NH_3-N would support maximal microbial growth under all feeding conditions.

There is at present no conclusive value of rumen NH_3-N concentration that will yield maximal growth of rumen microbes and at the same time increase the digestion of fibrous feeds. However, Preston and Leng (1987) suggested that the most important consideration is the maintenance of concentration of NH_3-N above 50 mg/l for most of the day, either by increasing the frequency of feeding or by the use of a slow release form of N.

Volatile fatty acids Volatile fatty acids from fermentation in the rumen

constitute the major source of energy for ruminants to meet their biochemical and physiological requirements. The molar proportions of VFA in the rumen are influenced by pH, which in turn is dependent on the composition of the diet.

Volatile fatty acids provide 50 to 85% of metabolizable energy used by ruminants that are fed a roughage diet (Owens and Goetsch, 1988). Van Houtert (1993) confirmed that only a small amount of energy was derived directly from plant carbohydrates as ATP during fermentation. Annison and Armstrong (1970) reported that VFA provide up to 70% to 80% of the energy for ruminants. Comparatively, acetate and butyrate are the principal oxidative energy sources, whereas propionate functioned as the major glycogenic VFA (van Soest 1987).

Reported results on the efficiency of acetate utilization as an energy source are conflicting. Orskov et al. (1979b) suggested that a mixture high in acetic acid is less efficiently utilized than those containing less acetic acid. He further reasoned that the amount of energy contributed by acetic acid as a proportion of the total energy derived from a high roughage diet is smaller, possibly due to the relatively low caloric value of acetate. Later, from the analyses of several research reports Orskov (1980) showed that a mixture containing as much as 75 molar percent of acetic acid could provide adequate glucose precursors, and growing animals fed such diets are unlikely to encounter energy deficiency. This view was later refuted by Preston and Leng (1987) who argued that ruminants fed low quality, high roughage diets where high acetate and low propionate are produced could developed a condition of glucose deficiency.

The optimum requirements of other acids, such as isobutyric, isovaleric, and valeric acids, by rumen microorganisms is difficult to quantify. Several researchers (Bryant, 1973; Dehority et al., 1967) mentioned that although these acids are required in small amounts they are essential for the growth of cellulolytic organisms and hence, improve cellulose digestion (Gorosito et al., 1985; Van Glyswyk, 1970). Earlier research (Cline et al., 1966) failed to show any positive effects of adding isoacids to a low protein diet, but studies of Miura et al. (1980) suggested that this could be related to the substantial amount of isoacids provided by the rumen microbes. Through the processes of sequential growth, lysis of other organisms (eg. *B. amylophillus*), and further deamination of N by *Megasphaera elsdenii* most of the isoacids are provided for the major cellulolytic bacteria such as *R. albus, R. flavefaciens, F. succinogenes and B. fibrosolvens.* Mean retention time (36 h) required for the degradation of dietary and microbial protein and for bacteria lysis to occur are considered major factors that will determine effects of isoacids on DM and fiber digestibility (MacGregor et al., 1983; Varga et al., 1984).

Minerals Other nutrients of concern are the minerals, particularly sulphur (S), phosphorus (P), magnesium (Mg), and trace minerals. Rumen microbes require micro and macro minerals for their metabolic functions. Specifically, S is required for optimal microbial growth and synthesis of S amino acids. A ratio of 14 parts N to 1 part S is required by ruminants (ARC 1980). About 8 g S/kg dry matter has been reported as the quantity found in microbial biomass (Bird, 1973).

Levels of S found in cereal straws and most forages are low, and therefore supplementation with a slowly released form of S is essential (Elliott and Armstrong, 1982). Durand and Kawashima (1980) reported that deficiency of other minerals including P are more important with processed industrial residues than with forages and unprocessed feedstuffs. The function of P is related to its major role in energy metabolism, acid-base balance, B-complex vitamins metabolism and a constituent of all nucleic acids (Tilman et al., 1986).

Forage legumes grown in tropical environments have been reported (Mackie and Therion, 1984) to have a higher mineral content than grasses under similar conditions. Kabaija and Little, (1987) reported from studies of several Ethiopian grasses and forage legumes that, except for sodium (Na), calcium (Ca), and P, most of the legumes contained adequate amounts of minerals which are required by ruminants.

However, availability of minerals found in forages is dependent on stage of maturity at which plants are harvested and the part of the plant that is used as feed (Loneragram, 1973). Buffering capacity, as it affects the physico-chemical characteristics of the rumen environment (Counotte et al., 1979), dilution rate (Owens, 1983; Thomson et al., 1978), and osmolity (Bennink, et al, 1978; Phillips et al., 1981) also affects availability of minerals. Chemical forms of minerals and their rates of elution from feed particles are important aspects that influence the digestibility and hence the overall utilization of minerals found in forages (Mackie and Therion, 1984).

C. Principles and Effects of Supplementing Low Quality Forages

The basic principle of supplementation is to ameliorate the deficiency of nutrients in the diet so as to optimize the utilization of the basal feed. Supplementation for animals fed low quality forages could include N, minerals, and energy to meet the growth requirements of the rumen microbes. However, the response that will be obtained from supplementation depends on whether the ingredient is capable of meeting the animals nutrient requirements above maintenance to carry out the specific physiological task (Preston and Leng, 1987).

Other supplements such as urea have been shown (Leng, 1990; Perdock et al., 1988) to increase intake and digestibility of low quality forages and rumen NH_3-N concentrations. Several studies (Adu et al., 1992; Mafwere and Mtenga, 1992) have indicated improvement in weight gain and overall feed utilization of lambs fed sorghum stover supplemented with urea or lablab. Others (Anis et al., 1991; Garcia et al., 1990) reported improvement in digestibility of DM and OM of grass hay but noted an increase in substitution rate with addition of forage legume to the diet. Maize grain supplementation to corn stover (Osuji et al., 1993c) resulted in improvement in digestibility of OM and DM, but also to a depression in corn stover intake. These negative effects could be related to the physiological state of the animal, associative effects between feed components, or changes in the rumen environment.

Supplementation of low quality roughages with forage legumes has the advantage of providing fermentable nitrogen, bypass protein, and critical minerals.

An additional benefit of forage supplements is to supply vitamin A, peptides and amino acids (Orskov ,1988; Ndlovu and Buchanan-Smith, 1985). A supplement that supplies required nutrients and therefore increase rumen microbial growth and numbers was useful for fiber digestion (Cheng and Costeron, 1980). Forage of higher quality and digestibility may also provide a suitable rumen environment for the attachment of microbes onto less digestible fractions.

Supplementation is usually carried out when there is insufficient forage nutrient to sustain the desired performance. Supplementation is usually for energy, N, minerals, or combinations of them. Energy is frequently supplemented at times of lower growth rate and milk yield in meat and dairy animals respectively, which are thought to have a higher requirement for energy than can be supplied from the feed (Journet and Demarquilly, 1980). Supplementation with high energy cereal grains has shown some negative effects compared to the use of forages. Reductions in microbial protein synthesis from 33 to 22 g/kg digestible organic matter (McMeniman et al., 1976), reductions in the rate and extent of fiber digestion, and increases in substitution rate (Hjink et al., 1981) have been reported when high energy cereal grains were used as supplements. Varga et al., (1990) reported an increase in efficiency of metabolizable energy (ME) used for maintenance and gain with Holstein steers fed alfalfa silage over those fed orchard grass. Higher ME concentration and less energy expenditure for ingesting and ruminating legumes compared to grasses were suggested (Weich 1986) to be major reasons for the difference.

A major goal of protein supplementation is to supply rumen degradable and nondegradable nitrogen to the rumen and small intestines. The effect is to enhance rumen NH_3-N concentrations, improve growth rates of microbes, and increase the digestibility of the forages. Cruickshank et al.(1985) reported increased organic matter intake, increased duodenal flow of nonammonia N, and greater digesta passage for legumes than grasses in lambs.

D. Characteristics of Forage Legumes

1. General classification

Legume crops have been important components in the development of agricultural systems around the world. Their earliest role was to provide soil nutrients, prevent erosion, and increase the carrying capacity of pastures. Legumes served as green manure with other crops, thereby replenishing soil organic matter and nitrogen. Under tropical conditions legumes are interspersed as cover crops with grasses pasture. Increased animal production from legume-grass mixed pasture has been reported by many researchers as far back as the sixties (Stobbs, 1969; Moore, 1962).

The nutritional and botanical characteristics of legume plants vary with species and growing conditions. Atkinson (1970) categorized tropical legumes into three major groups on the basis of the latitude in which they are found. Group 1 are legumes that are found in the latitudinal range of the Northern and Southern Tropics and consist of Rhychosia, Stylosanthes, Trifolium repens, T. vica, Lupinus,

Phaseolus medicago, Melilotus cassia, and Desmodium. Those legumes found in the intermediate North and South but mainly within the equatorial gap of 10 to 20° C latitude across the equator are placed in Group 2. These include Zonia, Galactica, Indigofera, Crotalia aeschynomene, and Astragalus. Group 3 are named the obligatory equatorial legumes and consisted of Alysicarpus calopogonium, Centrosema, Canavalia, Pueraria, and Teramus.

Tropical legumes can be grouped in two distinct categories based on their agronomic characteristics. Pasture legumes comprise the vast number of herbaceous climbing or crawling perennial and annuals that are found in the tropics, subtropics, and temperate regions. Most pasture legumes have served as cover crops, green manure, interspersed with other crops as a source of soil nutrients, or as short term pasture. Another category is the leguminous browses which include various types of shrubs, twigs, and trees with erect trunk and many branches. Most browses are perennial and biannual plants and are used for fencing, shade for other crops, and building materials. Most of the browse legumes are used as sources of feed for ruminants (alias multi-purpose trees), especially in semi-arid and arid environments.

A general agronomic description of tropical legumes is difficult, because there is a vast difference in characteristics between and within species. These differences are influenced by the habitat in which they are found, their climatic requirements, the presence of antinutrional factors, and the level of importance place on the plants within that region.

2. Chemical composition and nutritive value

The nutritive value of feed are determined by how well they supply adequate protein, energy, minerals, and vitamins. The capability of a feed to provide these nutrients in adequate amounts depends primarily on its inherent chemical composition.

Generally, the chemical composition of legumes is influenced by such factors as soil fertility, method of preservation, and the age at which it is harvested. Based on these factors, comparative information on tropical legumes is scanty although many studies have been conducted at various locations in the tropics and subtropics. Data on legume utilization by animals under field conditions are limited. Studies from intensive digestibility trials indicated that most tropical legumes are rich in protein, digestible organic matter, and essential minerals (Kabaija and Little, 1987). Forage legumes also supply rumen degradable N and when supplemented with cereal straw contribute a substantial amount of rumen degradable organic matter (Yilala, 1987). However, few data on energy content of tropical legumes are available, due in part to the cost of the equipment required to do such studies. Energy values obtained for several species of tropical legumes were from digestion trials (Milford, 1967). These values are commonly expressed as digestible dry matter, digestible organic matter, or total digestible nutrients. Minson and McLeod (1970) studied 543 tropical legume species and reported a mean DM digestibility of 54.0% (range 36.0% to 69.3%). Milford (1967) estimated average digestible crude protein percentage of DM to be 12 g/100 g of legume feed. Crude protein in

tropical legumes is digested with the same efficiency as that in tropical grasses with similar protein content. A lower crude protein value of 3.7 g/100 g of feed was reported by Butterworth (1967) for tropical grasses.

The concentration of minerals in tropical legumes is high, but it varies among and within species. Variations observed were in part due to the level of fertilization (Fisher, 1970), especially for P, Ca, Na, and Mg. Andrew and Thorne (1984) measured copper levels in several tropical legumes under various fertilization regimes and reported a range of 1.8 to 5.9 ppm, but suggested that these values were close to or below normal requirements for beef cattle.

Stage of maturity is one of the most influential determinants of the chemical composition of tropical legumes. Dry matter digestibility and crude protein content declined with increased stage of maturity. Milford and Minson (1968) reported a decline in nutrient value with increased stage of maturity for *LAB, CWP, Macroptilium atropurpureus, and Macroptilium lathyroides*. Santana, et al. (1989) studied the nutritive value of LAB fed to wethers in relation to its growth stage and observed that crude protein DM content, DM and crude fiber digestibility were highest at the flowering stage, whereas organic matter digestibility and crude protein and DM intake were greater at the milky stage. Crude fiber increased with an increase in the stage of maturity. Milford (1967) and Farinas (1965) reported mean values of 30.6% to 35.4% crude fiber respectively, in most tropical legumes. Other studies indicated the presence of some toxic factors that have been shown to have an adverse effect on reproductive performance of grazing animals

(Hamilton et al., 1970).

The present trend to develop integrated crop-livestock production systems has been the basis of much research in the tropics and subtropics. Legume plants have a unique place in this endeavor as sources of nutrients for humans and animals as well as for enhancing soil tilth. Other browse legumes such as Acacia, Sesbania, and Lacunae have shown some promise as sources of feed during the dry season, especially in arid regions of the Tropic and Subtropics.

Most of the research information available on tropical legumes was obtained more than 30 years ago (Minson, 1988) and is inconclusive. Therefore, there is a great need to assess the potential of these legumes as supplements to low quality forages in present livestock production systems.

Most pasture legumes, such as CWP and LAB have drawn some attention in recent years as potential sources of N and essential minerals. Thus, they could be used as supplements to low quality crop residues which is the primary source of feed for ruminant livestock in Sub-Saharan Africa.

3. Botanical history and nutritional characteristics of lablab and cowpea

a. Lablab *(Lablab purpureus)*, synonymous *Dolichos lablab*

Lablab is a member of a large family of phaseolus, which includes varieties of pulses commonly used for human food. Lablab is known by many common names within the various regions in which it is grown. Lablab is called Tongai bean (Engiand), Lubia (Sudan), Batao (Philippines), Feivi (Zambia), and poor man's

bean in most parts of Africa (FAO, 1988).

The LAB plant is a herbaceous annual or a short lived summer growing perennial. It is found widely in the tropics especially in Africa where it is cultivated mainly as a pulse crop for human consumption. Lablab requires a temperature greater than 29° C and is cultivated within a rainfall range of 400 mm to a maximum 2,500 mm. Lablab is tolerant to variable soil texture, but it requires well drained soils. The possibility of poor yield when grown in saline soil has been reported (Minson, 1990), but growth is normal in soil with a pH range of 5.0 to 7.5.

Nutritionally, LAB is compatible when sown as a companion with maize, sorghum, and millet. Lablab competes with weeds after it is established and is used often as a method of weed control. Compared with other pasture legumes LAB establishes quickly after planting because of its large seed that has a less resistant coat (FAO, 1988). The foliage of LAB is maintained for a longer time and therefore is sustainable as a source of feed compared to other pasture legumes. Regrowth occurred faster if the leaves were harvested without the branches and stems and yields of LAB are excellent when harvested either as hay or when used as silage (Milford and Minson, 1968).

Although LAB provides high nutrients for grazing animals, grazing management must be carried out judiciously to avoid pasture bloat. Hamilton et al. (1970) warned that animals should not be fed on LAB alone unless antibloat agents are applied before grazing. Feed flavor in milk and bloat are the most common problems observed with the use of LAB (Hamilton et al. 1970).

Lablab is also valuable as a deferred feed for dry season feeding. In Brazil and in most East African countries LAB is planted with maize and is grazed with the residues after the maize is harvested. Cultivar Rongai, CPI 1633 from Kenya and CPI 20212 (called Highworth in Australia, but it originated from Southern India) are the highest seed yielding and foliage DM producing cultivars commonly known. Cultivar Rogai is disease free under dry conditions, but it may suffer from stem rot caused by *Sclertinca sclerotiorum* under wet conditions (Milford, 1967).

Chemical analyses of LAB from various laboratories indicated a nutrient composition of N, crude fiber, and nitrogen free extract to be 5.84%, 55.3%, and 9.7% respectively (FAO,1988). Analysis of various parts of LAB harvested at different stages of maturity indicated that nutritional composition ranged from 11.7% to 26.44% crude protein, and 27.44% to 37.67% crude fiber (Minson and McCleod, 1970).

Various feeding trials to assess the performance of animals fed mixed LAB and grass diets have shown improvement in milk yield and weight gains. Minson (1982) reported that in Brazil, 47 bulls that were grazed in rotation on pastures of LAB, pigeon pea, and grasses gained an average of 40 kg per head in 63 days.

b. Cowpea (*Vigna unguiculata*)

The botanical name *Vigna uguiculata* and the origin of this tropical pasture legume have been controversial. Unlike LAB which is known by many common names around the world, CWP or Southern bean (as commonly called in some U.S. Southern States especially Georgia) are the only names used to refer to

CWP. The Royal Botanical Gardens, considered CWP as the general name and that other varieties were cultivars. Varieties of CWP are usually categorized into three groups by using the shape and size of beans as the major criteria. Variety *sinesis* is the most common CWP and has medium sized kidney shaped or roundish beans. Variety *V. sesquipedalis* has an elongated kidney shaped seed. whereas *V. cylindrica or catjang* has small oblong cylindrical seeds. Cowpea is widespread throughout the tropics and subtropics, however, its country of origin is uncertain.

Cowpea is a herbaceous annual with twining stems that are erect and bushy. The leaves are trifoliated, and flowers occur in axillary raceme on stalks 15 to 30 cm long. The seeds of CWP are variable in size and color, but are usually 4 to 8 mm long and 3 to 4 mm broad. Cowpea plants prefer warm moist climate, but can survive in hotter climates with a daily temperatures of 27°C. Cowpea is found between latitudinal limits of 30o north and south of the equator, and grows well up to 1,500 m elevation. The plant grows well under rainfall of 750 to 1,100 mm and is tolerant to drought conditions, but it is less productive under flooding conditions. Well drained clay soils tend to encourage vegetative growth (FAO, 1988).

Limited information is available on the nutritional value of CWP. However, organic matter digestibility of forage 49.1% has been observed with cattle (Minson and McCleod, 1970). Continous field drying for more than 8 days has been reported (Minson, 1990) to reduce DM digestibility by 4%.

E. Some Field and Laboratory Methods of Evaluating Forages

1. Laboratory analysis

Field trials and laboratory methods are used to evaluate feedstuffs for ruminants with each having its own objective. Usually laboratory methods such as the proximate analysis are conducted at an early stage of a feed evaluation process to quantify the nutrient profile of the feedstuffs under study. Data concerning digestibilty of DM and organic matter, total and available N, fiber components, and sometimes minerals are collected at this stage.

Samples of feed to be used for laboratory analyses are taken from supplies that are conserved for feeding during the field trial. Such samples are required to be representative of the feed being fed to avoid inaccurate estimation of nutrient content (Preston and Leng, 1987).

Treatment of feed samples in the laboratory also plays an important role in the accuracy of the results. The most appropriate temperatures for drying samples to reduce moisture content is still being debated internationally. Lack of reliable data on the effects of high temperature (100°C) and lower temperature (70 to 60°C) which could be used to standardized the drying procedure has been one of the reasons for variation between laboratories (ARC, 1987). High protein feeds are sun-cured or dried at lower temperature to avoid volatilization of nitrogenous compounds (Osuji et al., 1993b). The Goering and van Soest method (1970) is usually used to separate fiber components, including NDF, acid detergent fiber (ADF), and lignin in forages. Neutral detergent fiber is commonly used in most

laboratories as a better measure of fiber than crude fiber (Chesson, 1986; McAllan and Griffith, 1984), however, there have been debates about whether NDF adequately represents the plant cell wall because of the high pectin content (Morrison, 1980). Earlier studies by Robertson et al. (1986) and Ulyatt et al. (1984) suggested that in ruminants, pectic substances are rapidly degraded by microbes in the rumen and hindgut. Englyst and Cummings (1984) also reported that degraded pectic substances are available like other storage carbohydrates.

General relationships among the chemical composition of a feed, its palatability, intake, and nutrient availability are not straight forward as sometimes portrayed in most prediction equations (van Soest, 1987). These factors are influenced by the existence of heterogenous cell populations within the plant, with some structures being thick and lignified (van Soest, 1987). The existence of structural differences between plant types and the different parts used as feed are possible reasons for the limited use of prediction equations to estimate nutrient availability.

2. In situ degradation technique

Determination of nutrient availability is influenced by level of feed intake, interactions among feed components, and passage time, especially for structural carbohydrates. An approach has been to estimate the bioavailability of N and DM on a time dependent basis, taking into consideration the dynamic nature of digestion. Quin et al. (1939) developed the silk bag method for describing both the

rate and potential extent of digestion with time for feeds suspended in a porous bag in the rumen. The underlying theory was that loss of test feed from a bag suspended in the rumen of fistulated animals fitted with a rumen cannula could estimate nutrient degradation in the rumen.

This method has been improved by other scientists (van Keuren and Heinemann, 1962 and Erwin and Elliston, 1959), but the basic theory was maintained. Orskov et al. (1980); Orskov and McDonald (1979), developed an equation $(P = a + b\,(1 - e)^{ct})$ that described the disappearance of substrates from a dacron bag incubated in the rumen of fistulated animals. The equation described the degradation constants a, b, and c(k_b) of DM and N. The curve of both N and DM are described as:

Within a Lag Time (LT), Y = A

Beyond the Lag Time (> LT), $Y = a = b(1-e^{-ct})$

Where; a, b, c(k_b),, are the degradation constants.

p is the amount of DM or N degraded at time t.

a is the rapidly degradable fraction

b is the amount which in time will be degraded in the rumen

c = (k_b) is the fractional rate constant at which the b fraction will be degraded per hour

Potential degradability (Pd) = (a+b)

The in situ bag technique is used at present by many researchers (Michalet-Doreau and Cerneau, 1991; Madsen and Hvelpiund, 1985) to determine the

degradation kinetics of feeds. Significant differences have been reported from intralaboratory (Lindberg et al., 1984) and interlaboratory (Oldhman, 1987) studies. Bag porosity allowing loss of undegraded materials (Sertala, 1983; Weakly et al., 1977), difficulty of influx and reflux of microbes (van Hellen and Ellis, 1977; Lindberg et al., 1984), and clogging of pores in the bag (Nocek and Hall, 1984) are causes of the variation reported. Fine ground materials tend to leave the bag faster and may overestimate degradation rates (Olubobokun et al., 1990; Nocek, 1985). Wide variations in degradability has been observed with sample weight to bag surface area ratios that are not constant (Uden and van Soest, 1984). Degradation of feeds is also influenced by the method of introducing the bag in the rumen. Nocek (1985) recommended that bags should be introduced at different times and all bags recovered at the same time to reduce variation as a result of an interruption in digestion. However, others (Williams et al., 1989; Dehority and Orpin, 1988) suggested that if feeding is done more than once daily, there could be osmotic shock effects, entering of oxygen, and change in temperature after feeding. The same authors (Williams et al., 1989; Dehority and Orpin, 1988) recommended that introduction of the bags in the rumen at the same times and removing at different times should be practiced.

Location of bags in the rumen(Hawley, 1981; Yang and Varga, 1989) and number of replications and animals are other factors that can influence the results obtained from in situ degradation studies. Mertens (1993) reviewed the use of the nylon bag technique and concluded that its major advantage over *in vitro* methods

is that it measures the combined effects of diet and animal on digestion of a feed which normally are not measured in *in vitro* studies.

3. Use of markers to measure passage kinetics

Rate of passage of feed particles through the digestive tract is influenced by level of feed intake and digestion. The process of mixing feed with digestive juice and enzymes of bacterial origin, segregation, and passage to the lower tract are regulated by many interactions in the rumen (Sutherland, 1987; Martz and Belyea, 1986).

The earliest model of passage rate was proposed by Blaxter et al. (1956) who suggested a two compartmental pool (rumen and abomasum), but their theory was not widely accepted. Grovum and Williams (1973) reintroduced the model of Blaxter, but proposed that the two compartments were the rumen and cecal-proximal colon. Another theory of Blaxter et al. (1956), which proposed the concept of selective retention using stained particles, has recently been confirmed by Cherney et al. (1991) who observed that large and small particles have different retention times. Evans (1981) explained that forage diets have a higher rate of passage than high concentrate diets due in part to increased rumination and greater saliva flow to the rumen. Physical form of the feeds such as processing that reduces particle size and increases level of intake, lead to higher rates of passage (Mertens et al., 1993)

Efforts to understand the dynamics of particulate and liquid phases of digestion

had lead to the concurrent use of liquid and solid markers on the assumption that each has different turnover rates. (Uden et al., 1980). Migration of markers to other particles in the rumen, weak binding of markers to feed particles at low concentration, absorption into the animal cell, and precipitation are some problems that have been associated with solid markers. At present, the two most useful markers are chromium mordanted fibers for solid phase and chromium or cobalt ethylenediamine tetraacetic acid for liquid. Uden et al. (1980) reported their recovery to be about 97% to 99 % in the feces and only 1% to 3% in the urine.

4. Measurements of microbial protein synthesis

Microbial protein flowing from the rumen and dietary protein escaping degradation in the rumen provides amino acids for absorption from the intestine. Availability of amino acids is, therefore greatly influenced by the growth rate of rumen microbes. This has lead to the development of several methods to estimate microbial protein.

Diaminopimelic acid (DAPA), amino ethylphosphoric acid (AEP), ribonucleic acid (RNA), adenosine triphosphate (ATP), various compounds containing radioactive sulphur, and recently urinary purine derivatives (UPD) have been used as markers. Each of these methods has individual limitations, but they do tend to provide some information on microbial protein synthesis.

Weller et al. (1958) used DAPA as a marker to estimate bacterial protein synthesis based on the fact that the marker is found in ruminal bacterial cells but

not in plant tissues. The possibility that DAPA could be detected in protozoa from ingested bacteria was reported by Stern et al. (1977) and Colemen and Hall (1969). The procedure consisted of estimating bacterial N from previously determined ratios of DAPA to N in mixed rumen bacteria. Amino ethylphosphoric acid (AEP) has also been used as a marker to determine protozoal numbers in the rumen (Ibrahim and Ingalls, 1972). Czerkawski (1974) used both DAPA and AEP to estimate total microbial protein synthesis. The weaknesses of DAPA and AEP were that the accuracy was based on a constant ratio of DAPA to N and therefore maintenance of a constant ratio of microbial species is required. Variation within species (Work and Dewey, 1953) and the presence of lysed bacterial cell walls in the rumen are conditions that could lead to overestimation (Orskov 1988).

Ribonucleic acid (RNA) has been used (Smith et al., 1978) to estimate the extent of dietary N conversion to bacterial and protozoal N. The procedure relies on the assumption that all dietary RNA is degraded in the rumen and that a constant proportion of the total microbial N is nucleic acid N (McAllan and Smith, 1973). Diets with lower degradability and higher outflow rates may allow some dietary nucleic acid to escape to the small intestine, and therefore the method tends to overestimate microbial contributions to the small intestine (Orskov, 1988; Smith et al., 1978).

Radioisotopic labelled substances have been used widely as microbial markers (Kennedy and Miligan, 1978; Nikolic, 1977; Walker et al., 1975). Similarly, ATP has been used as rumen microbial marker (Forsberg and Lam, 1977) but variability in

the concentration of ATP in rumen microes has been observed (Jensen, 1977).

Urinary purine derivatives (UPD) received some attention recently as microbial markers (Orskov, 1988; Chen, 1990b). This method is based on the assumption that about 83% of microbial nucleic acid is digested in the small intestine. The method was developed such that the ratio of the concentration of UPD or allantoin to creatine in spot urine or plasma samples could be used to diagnose the nutritive state of the animal (Chen et al., 1992; Osuji et al., 1993b). Allantoin, uric acid, xanthine, and hypoxanthine are excreted in the urine. Differences in purines have been reported between cattle and sheep (Chen et al., 1990a). Verbic et al. (1990) explained that the differences were due to the activity of xanthine oxidase in the blood of the intestinal mucosa. An advantage of the UPD method is that it is simple and nonfistulated animals are used in comparison with other markers that require fistulated animals from which to collect digesta from the duodenum.

The various techniques described in this review have all been used under many conditions, and variability between studies have been mentioned. The type of marker used, coupled with numerous factors that influence microbial protein synthesis, could in part explain the large variation reported. Stern and Hoover (1979) suggested that rate of ruminal degradability of substrates, dilution rates, and frequency of feeding are factors that affect the efficiency and rate of microbial protein synthesis.

F. Summary of Literature Review

The abundant crop residues found in SSA could be more useful if ruminant diets were supplemented strategically with locally grown feeds. It is obvious that this would improve the performance of the large population of livestock. However, the utilization of these low quality forages is influenced by many nutritional and animal factors. Some of these include inherent characteristics of the feedstuffs, conditions in the rumen, interactions among microbes, physiological state, and previous nutritional history of the animal.

Numerous methods are available to evaluate feedstuffs for animals, and some have been used extensively as established methods, perhaps due in part to their accuracy and lower cost. There are other methods that could also be useful, but their applications are limited because of their low repeatability, and large amount of time required for sample collection, type of experimental conditions, and cost of data collection and analysis. While newer and more accurate methods are being developed, the present techniques should remain useful as methods of evaluating feeds for animals.

CHAPTER II. MATERIALS AND METHODS

A. Description of Experimental Materials

1. Experimental site, feedstuffs, and research animals

The following experiments were conducted at the Debre Zeit Research Station, a sub research center for the International Livestock Center for Africa (ILCA). Debre Zeit is situated about 50 km North-West of Addis Ababa at an altitude of 1920 m and has an average rainfall of 875 mm (Ummunna, 1993). Cowpea and LAB were grown on vertisol soil, which is the most common soil type around the station. Both legume supplements were harvested at the flowering stage and were air dried before storage. The sun-cured CS that was used as the basal feed was purchased from local farmers within the Debre Zeit area. Ethiopian Menz sheep, which are sometimes called Menz-type sheep were used for the experiments. The sheep have thick wool, a fat tail, and an average mature weight of 45 to 50 kg. The sheep were purchased from the local market. There was no information available about their age, and therefore, their body weights were used to group them into experimental blocks.

2. Experimental protocol

Two studies consisting of five experiments were conducted to evaluate CWP and LAB hays as supplements to sun-cured CS fed to sheep for ad libitum intake. Different groups of mature sheep were used in Experiments 1, 2, and 3, whereas

one group of weaned lambs were used in Experiments 4 and 5. During the initial stage of Study 1 laboratory analyses were also conducted to determine the nutrient composition of CS, CWP, and LAB. In Study 1 CWP and LAB were fed separately or in combination as supplements to CS which was provided for *ad libitum intake* to mature Ethiopian Menz sheep. The average quantity of LAB, CWP, or a mixture of both supplements fed to the sheep was 282.2 g DM/d (Table 1). Degradation kinetics of CS, CWP, and LAB were studied in Experiment 1, whereas passage rates and digestion kinetics of the feeds were estimated in Experiment 2. Feed intake and digestibility of DM, NDF, N, and GE, ruminal fluid pH, concentrations of VFA and NH_3-N, and N balance were measured in Experiment 3.

Table 1.Quantities of cowpea and lablab fed as supplements to corn stover in Study 1

Feeds	A	B	C	D	E	F
			g DM/d			
Lablab	-	282.9	196.6	141.2	85.2	-
Cowpea	-		85.5	141.3	195.9	280.4

Corn stover, mineral block, and water were provided for ad libitum intake.
Locally made mineral block consisting of ground soil, salt, and molasses was offered for ad libitum intake.

The effects of supplementing four levels of CWP (Table 2) to CS fed for ad libitum intake to Ethiopian Menz weaner lambs on nutrient utilization and growth performance were measured in Study 2. In Experiment 4 the same parameters as measured in Experiment 3 were estimated in addition to urinary purine derivatives as a measure of microbial N supply. In experiment 5 twelve week growth rate of

lambs fed CS supplemented with four levels of CWP was measured. Lambs were removed from the individual feeding pens and transferred into metabolism crates for 7 days at the end of the 4th and 12th week of the growth trial to measure feed intake and digestion, rumen metabolites, and urinary purine derivatives. Cost of feeds, lambs, labor, weight gain, feed conversion efficiency, and percentage of CS substituted for CWP were compared under the five dietary treatments to estimate the economics of CWP supplementation.

Table 2. Quantities of cowpea fed as supplement to corn stover in Study 2

Feeds	C0	C1	C2	C3	C4
			g DM/d		
Cowpea	-	133.9	267.5	397.1	524.5

Corn stover, mineral block, and water were provided for ad libitum intake.
Locally made mineral block consisting of ground soil, salt, and molasses was offered for ad libitum intake

B. Characteristics of Corn Stover, Cowpea, and Lablab (Experiment 1 and 2).

1. Nutrient composition

The nutrient composition of CS, CWP, and LAB hays were determined from chemical analyses using common laboratory procedures (AOAC, 1985). Air dried samples (100 g) of each feed were ground through a 2 mm screen and stored in sealed plastic containers. Analyses were done for DM, GE, N, acid detergent insoluble N (ADIN), NDF, ADF, lignin, and several macro and trace minerals.

a. Dry matter

Five grams air dried samples of each feed were weighed into porcelain crucibles which had been oven dried at 105^0 C for 30 minutes. Weight of the sample and crucible was recorded, and both were placed in the oven at 105^0 C for 12 h. Dry matter of the sample was determined by difference from the weight before and after oven drying.

b. Gross energy

Dried feed and feces were each pelleted by using a pellet press equipped with a 1 g sample mold. Two pellets were made from each sample. Combustion of pelleted feed and feces was used to determine their respective GE. One hundred milliliters of urine was measured into a 150 ml beaker. The pH of the sample was determined with a pH meter (Kent EIL 720). Urine samples that had a pH below 5.5 were treated with sodium carbonate solution (10 % w/v) to bring the pH between 5.5 to 6.0. This was done to prevent crystallization and increase the solubility of the nutrients. Twenty-five milliliters of the urine was poured into crucibles which had been lined with 13 cm diameter polyethylene sheets. Weights of the crucible with polytene lining, and urine plus crucible with lining were recorded. The crucibles containing urine were placed in a vacuum oven at 30^0 C. The pressure of the oven was set at 381 mm Hg for 24 h. After 24 h the pressure was increased to 635 mm Hg, and remained there for 48 h. Dried urine with polytene was placed in a bomb calorimeter to determine the GE of the sample. Heat generated from the polytene sheets was measured and subtracted from the

total GE to determine the GE in the urine.

c. Total and available nitrogen

Total N was determined by the Kjeldahl method using a 1026 Tecator Kjeltec Digestion and Distillation System. Nitrogen content of the ADF fraction was considered as ADIN. Difference between the total N in the sample and ADIN was considered as N available to the animal.

d. Fiber components

Neutral detergent fiber, ADF, and lignin were determined with neutral and acid detergent solutions, respectively, using the methods described by Goering and van Soest (1970). Five g of each feed sample were weighed into a 75 ml beaker. Fifty ml of ADF or NDF solution were added gently into each beaker with the sample. The beaker was placed on a heating manifold and allowed to boil for 1 h. Each sample was removed, transferred into a refluxing crucible, and washed three times with hot water. The washed sample was rinsed twice with acetone to remove all non-fiber materials. The remaining residue was allowed to air dry for 30 minutes and thereafter placed in an oven at 105^0 C for 24 h. The difference in weight before and after treatment with NDF or ADF solution was used as the weight of ADF or NDF.

One hundred milliliters of prechilled 72% H_2SO_4 were added gradually in quantities of 25 ml to the ADF residues in the crucible containing the fiber and placed into a 150 ml beaker. The mixture was stirred gently with a glass rod at an interval of 30 minutes to break up the fiber lumps. The process of adding the acid

and stiring continued until a paste was formed. The stirring process continued at an interval of 30 minutes for 3 h at which time all the acids had filtered out of the crucible into the beaker. The residues in the crucible were washed five times with hot water and rinsed twice with acetone. The washed fiber residue was placed in an oven at 100° C for 24 h, and was later incinerated at 450° C for 6 h. The difference in weight loss upon ashing of the fiber residues was considered as the weight of crude lignin.

e. Macro and trace minerals

A 0.5 g sample of ground feed was transferred into a 75 ml micro-digestion tube. Four ml of concentrated H_2SO_4 and 2 ml of H_2O_2 were added to each tube and placed on a digestion block which had been pre-heated to 270° C. The tubes were heated for 30 minutes, then removed from the digestion block and allowed to cool. Another 2 ml of H_2O_2 were added to each tube, and the sample was placed on the digestion block and heated for another 30 minutes before allowing to cool again. The process of adding 2 ml of H_2O_2, heating for 30 minutes, and cooling was repeated until a clear white supernatant appeared. The clear color was used as an indication that oxidation and digestion were complete. Fifty ml of distilled deionized water were added to each tube, mixed thoroughly, and the insoluble materials were allowed to settle for 3 h. Analysis for K, Ca, and Mg was carried out by diluting the supernatant 20 times with 0.1% lanthanum and read by atomic absorption spectrophotometer (AAS). Sodium, iron (Fe), manganese (Mn), and zinc (Zn) were read directly from the digestion tubes by atomic absorption without the

addition of lanthanum.

2. Degradation kinetics of feeds (Experiment 1)

a. Experimental design, animal feeding, and management

The *in situ* technique using synthetic fiber bags as described by Orskov and McDonald (1979) was used to determine degradation characteristics of CWP, LAB, and CS at various times of incubations.

Eighteen mature fistulated sheep (6 treatments x 3 replications) with an average body weight of 27.2 kg (sd. 2.25) were selected, weighed, and placed into three blocks of six animals on the basis of their live weight. Six dietary treatments (Table 1) consisting of LAB and CWP fed separately or in combination as supplements to CS were randomly allocated to the animals within each block. The supplements were fed separately in plastic pails, whereas CS was provided for ad libitum intake in a different feeding pan. Supplements were fed at 8:00 AM, followed by feeding CS two hours later. This feeding procedure ensured that the supplements were completely consumed before the animals were given CS. Mineral blocks that were made from wet soil with 25% table salt added were provided free choice. Fresh drinking water was available throughout the day. The period of adjustment to diets lasted for 14 d during which time the daily quantity of CS fed was increased from 700 to 900 grams, an increment of 58% to 74% of total feed offered to each sheep daily. Orts were collected daily and stored at room temperature for chemical analysis to determine the actual nutrients consumed by

each animal. All of the daily supplements were consumed by the 10th day of the adjustment period. The animals were housed in individual feeding pens with slatted wooden floors.

b. In situ degradation procedure

The method for the *in situ* study developed at the International Livestock Center for Africa (ILCA) was based on a standardized type of synthetic fiber (Polymon) with a pore size of 41 μm^2, and a surface area of 6.5 x 14 cm^2. The bags were reused by washing and drying after each experiment. Three g of feed ground through a 2 mm screen were put into dried preweighed bags. The edges of the bags were sealed with a water resistant glue to prevent the leakage of feed particles

Four bags were tied together with a thin nylon cord. Two sets of four bags were tied to a second cord which passed through a flexible rubber hose. Eight bags were incubated in the rumen of each sheep for 0, 6, 8, 12, 24, 48, 72, and 120 h. The bags and tubes were immersed in the rumen of each animal as deep as possible. Each set consisting of eight bags for the respective period of incubation was connected to another cord of 25 cm with a portion of the cord hanging outside of the canula. Bags were placed in the rumen at the same time and removed periodically at the end of each incubation period.

After removal from the rumen each set of bags was washed under running water to remove all attached rumen digesta from the surface. The bags were further washed in a laundry machine for six cycles of 5 minutes each with another

set of bags which had not been incubated in the rumen. The washed bags with residual feed were dried at 60° C for 48 h. Feed residues were removed from the bags and stored for determination of DM and N. Weight loss from the nonincubated sample was used to determine washing loss. Dry matter and N loss were calculated as the differences between the weight of feed incubated and the residue remaining after incubation. Degradation kinetics of DM and N were calculated using the equation of Orskov and McDonald (1979) on page 43.

3. Passage kinetics of feeds (Experiment 2)

a. Experimental design, animal feeding, and management

Kinetics of passage of CWP, LAB, and CS through the gastro-intestinal tract for liquid and particulate matter were studied by using the method of Uden et al. (1980). Eighteen nonfistulated mature sheep with an average body weight of 24 kg (sd. 1.5 kg) were placed in three blocks containing six animals each. Six dietary treatments as shown in Table 1 were randomly allocated and fed to the sheep within each block. The animals were adjusted to the diets for 14 days. Housing, feeding, and management were the same as in Experiment 1.

b. Preparation and administration of markers

Eight hundred g each of CS, CWP, and LAB consisting of a mixture of stalks and leaves were washed thoroughly with tap water to remove all dirt and foreign matter. An equivalent of 33% (wt/wt) of Na_2Cr_2O was added to washed feed material and placed in enamel buckets. The mixture of Na_2Cr_2O and feed were

thoroughly mixed and water was added until the mixture was totally submerged. The top of the container was covered with aluminum foil and tied firmly with a heat resistant cord. The buckets containing the mixtures of feed and Na_2Cr_2O were placed in an oven and baked at 100^{0}C for 24 h. The solution from the baked materials was disposed of according to chemical safety guidelines. Each mordanted feed was washed several times with running tap water until the supernatant was faintly clear. The washed materials were again returned to the buckets, and 480 g of Ascorbic acid ($C_6H_8O_6$) equivalent to 60% of the starting weight of material were added. The mixture was soaked in water for about an hour until the pH was between 4 and 4.5. The mordanted feeds were washed again with running water, oven dried at 65^{0}C for 72 h, and stored until feeding.

Cobalt ethylenediamine tetraacetic acid (Co-EDTA) was used as a liquid marker. Thirty-two g NaOH, 297.2 g Na-EDTA, and 190.4 g $CoCl_2.6H_20$, were dissolved in 1600 ml of distilled water. The mixture was gradually heated to 50^{0}C and later allowed to cool to room temperature. One hundred and sixty ml H_2O_2 were added, stored at room temperature for 4 h, and mixed with 2400 ml of 95% (v/v) ethanol. The mixture was refrigerated until the time of administration. The ratio of complex chemicals to water used for preparing the solution was 1 g to 20 ml, respectively.

Fifty milliliters of Co-EDTA solution was administered into the rumen with a 100 ml syringe attached to a drenching tube. After drenching, each sheep was fed 20 g of dried mordanted CS, LAB or CWP within 45 minutes before the usual morning

feeding. Fecal samples were collected at 8, 12, 18, 24, 30, 36, 48, 60, 72, 96, 120, and 144 h post-administration of the markers. The fecal samples were oven dried at 60^0 C for 24 h, ground through a 2 mm screen, and stored for analysis. Another sample was dried at 100°C for 24 h for DM determinations. Similar procedures of feeding the mordanted feed and administering the liquid marker were carried out independently for CS, CWP, and LAB. Two week intervals were allowed between the administration of markers for each feed.

Ground fecal sample dry weight of 0.5 g was put into 75 ml digestion tubes. Acids were added to the tubes in the sequence of 1.5 ml concentrated H_2SO_4, 2.0 ml 60% $HCLO_4$, and 3.0 ml concentrated HNO_3. The tubes with samples and acids were placed on a block digester preheated to 150^0 C. Digestion was carried out at 150^0 C for 1 h followed by an additional 1 h digestion at 200^0 C. The contents of the tubes were cooled and 50 ml of water added and mixed gently. The insoluble matter was allowed to settle for 12 h. Concentrations of cobalt and chromium were determined by AAS. Kinetics of liquid and particle passage using marker concentrations were calculated by the method of Grovum and Williams (1973) as described in the equation below:

$$Y = 0 \text{ when } t < TT$$

$$Y = Ae^{-k1(t-TT)} - Ae^{-k2(t-TT)} \text{ when } t \geq TT$$

Where: Y and A are adjusted marker concentration in fecal DM

K_1 and K_2 are passage rate constants for rumen and hindgut, respectiveiy

TT is calculated time of first appearance of the marker in the feces

t is sampling time (h) after administration of marker

Regression analysis using the natural logarithm of marker concentrations plotted against collection times was used to estimate the Y intercepts and the second slowest rate constants K_2. Thus transit time, half-life, mean retention time, and flow rate were calculated as follows for both the liquid and solid markers:

Transit time (TT) = $(A2-A1)/(K_2-K_1)$

Half-life (t½) = $0.693/K_1$ or K_2

Mean retention time (MRT) = $(1/k_1 + 1/k_2) + TT$

Flow rate (FR) = F + (1 - OMADR)DDMI

where: DDMI = digestible dry matter intake

OMADR = organic matter actually digested in the rumen. Values of 0.65 have been used for forages (ARC, 1984) but 0.75 for straw based diets (Osuji et al., 1993a) was used in this study.

Therefore, FR = F + .25 DDMI

FR = V*K1 then $V = FR/K_1$ (Faichney, 1975)

Where : A1, A2 are natural logarithm derivatives of the Y intercepts

K_1 and K_2 are respective passage rate constants from the rumen and hindgut

F is fecal outflow rate per h as estimated from digestion study.

DDMI is digestible dry matter intake as estimated from digestion

study using a digestibility value of 0.75 for straw based diets

0.693 = constants from Grovum and Williams (1973)

Digestion kinetics of rumen NDF intake, rate of passage, and digestion were calculated using the models of Robinson et al. (1987), which assumed a steady state condition in the rumen.

The models are expressed in the following equations.

Rate of intake (k_i; kg/h) = 1/24 X (intake, kg/day)/rumen pool size, kg)

Rate of passage (k_p; kg/h) = 1/24 X (fecal flow, kg/day)/rumen pool size, kg

Rate of digestion (K_d; kg/h) (K_i - K_p)

C. The Effects of Supplementing Corn Stover with Cowpea and Lablab on Intake, Digestion, and Metabolism of Nutrients (Experiment 3)

1. Experimental design, animal feeding, and management

The effects of supplementing CS with CWP and LAB separately and in combinations on intake and digestion of DM, NDF, N, and GE and concentrations of rumen metabolites were evaluated. Ruminal fluid pH, concentrations of VFA and NH_3-N, and N retention were used to determine the extent of nutrient metabolism in the rumen. The six dietary treatments are as already shown in Table 1.

Twenty four mature male sheep with an average body weight of 23.7 kg (sd.

2.45 kg) were placed into four blocks of six animals. The dietary treatments were randomly allocated to each animal within a block. The animals were adjusted to the diets in individual pens for 14 days and later moved to the metabolism crates. All the animals were housed in individual metabolism crates with iron mesh floors, wooden walls, and removable feeding pans. Removable feeding pans were used for the daily measurement of feed intake and orts. The animals were fitted with canvas fecal collection bags for the daily collection of total feces excreted. A rubber funnel-like urine collection apparatus with tubes attached and suspended in a three liter pail containing 75 ml of 10% H_2SO_4 were attached to each animal. Fecas and urine were collected for 7 days. Fresh drinking water and mineral blocks were provided free choice. The study was carried out in two consecutive periods, using 12 animals per period. The first group of 12 animals was transferred to the metabolism crates on the 10th day of adaptation and remained there for an additional four days of adjustment to the crates. The second group of animals was brought into the individual feeding pens to start their adjustment period. Management, feeding, and sample collection were identical for both periods.

2. Sample collection

Samples of 50 ml from daily urine collected were stored and pooled for each animal at the end of the 7 day collection period. Ten percent of the pooled feces excreted daily over the 7 day period was saved, pooled for each animal, and stored under refrigeration. One hundred g subsample of mixed feces was taken,

oven dried at 60°C for 24 h, ground through a 1 mm screen, and stored for analysis for DM, NDF, N, and GE.

Ruminal fluid were collected by using a stomach tube on the 8th day at 0 (pre-feeding), 1, 2, 3, 4, 6, 8, and 12 h post-feeding. One hundred ml of fresh rumen fluid was stored in sealed plastic cups and sent immediately to the laboratory to determine pH. After homogenizing with a stirring bar the pH was measured with a Kent EIL 7020 pH meter within 1-2 minutes after sampling. The time required for reading each sample lasted for about 30 seconds. Another portion was acidified with 8 drops of concentrated H_2SO_4 and frozen for the determination of NH_3-N and VFA. Ten ml of thawed rumen fluid was put into 75 ml digestion tubes containing 15 ml of distilled water. Ammonia N concentrations were determined by distillation with a 1026 Kjeltec Distillation System. The distillate was titrated with .09 N hydrochloric acid (HCL). Another 5 ml was removed and placed in 10 ml tubes to determine the concentration of VFA using a Gas-Liquid Chromatograph (Pye Unicam Series 304) fitted with a flame ionization detector.

D. The Effects of Supplementing Corn Stover with Graded Levels of Cowpea on Intake, Digestion, and Metabolism of Nutrients (Experiment 4)

1. Experimental design, animal feeding, and management

Thirty growing lambs with an average body weight of 20.5 kg (sd. 2.4 kg) were selected to study the effects of supplementing CS with increasing levels of CWP on intake, digestion of DM, NDF, N, and GE and concentrations of rumen

metabolites. Ruminal fluid pH concentrations of VFA and NH_3-N, N retention, and microbial N supply were used to determine the influence of supplementation on nutrient metabolism. The lambs were placed into six blocks of five animals each. The dietary treatments are shown in Table 2. The animals were randomly allocated to the five treatments within each block. Fifteen of the thirty lambs were fed the same quantity of CWP in two parts twice daily, whereas the other group was fed once per day. The second portion of CWP was offered 4 h after the first supplementation. The experiment was conducted for two periods with twenty animals per period. Feeding, housing, and management, housing were the same as in Experiment 3.

2. Sample collection

Method of sample collection was similar to Experiment 3, except the procedure of urine sampling for purine derivative analysis. The procedure for estimating microbial N supply from urinary purine derivatives were as described by Chen et al. (1990b). Total urinary purine derivatives (uric acid, allantoin, xanthine and hypoxanthine) were analyzed from daily urine collected and pooled for the 7 day period.

Two liters of urine were diluted with water to a final volume of 4 liters, and 100 ml were frozen for analysis of purine derivatives to estimate microbial N supply. The urine samples were further diluted in the laboratory with 1 ml of diluted urine + 29 ml distilled H_2O to determine allantoin and 1 ml diluted urine + 7 ml H_2O for the

analysis of uric acid.

E. Growth Performance of Lambs and Economics of Cowpea Supplementation (Experiment 5)

1. Experimental design, animal feeding, and management

Thirty lambs with an average body weight of 20.1 kg (sd. 1.46 kg) were purchased from the local livestock market. The average price was 85 Ethiopian Birr (US$ 17.00) per head. Information obtained from farmers indicated that the lambs had been fed CS or grass hay daily after browsing during the day on branches of trees and shrubs. The sheep were quarantined for 21 days, and were drenched and sprayed for endo and ectoparasites, respectively. At the end of the quarantine period the lambs were weighed and grouped according to body weight into six blocks of five animals each. Five dietary treatments as shown in Table 2 were randomly allocated to animals within each block. Fifteen of the thirty lambs were fed the same quantity of CWP in two parts twice daily, whereas the other group was fed once per day. The second portion of CWP was offered 4 h after the first supplementation. Locally made mineral blocks, water, and CS were provided for ad libitum intake. The lambs were adjusted to the diets within 14 days.

2. Sample collection

Daily quantity of feed offered and orts were recorded for 84 days. Average of two weeks feed intake was calculated periodically to determine the incremental

change in feed consumption.

Twenty-four h starved body weights were taken at the beginning (W1) and end of the adjustment period (W2) and thereafter for every two weeks (W_n). Incremental weight change (WC) was calculated as the difference between previous and present weight (eg. WC = W2 -W1). The experiment lasted for 84 days including the adjustment period. All supplement for each treatment was consumed daily. Three lambs died from the CS fed group during the 4th week of the growth study.

Economics of supplementing CS with graded levels of CWP was evaluated using cost of inputs and price of output as indices. Average purchase price of lamb was used to determine the cost of mortality. Average daily DM and CS intake, average daily weight gain (ADG), feed conversion efficiency (FCE), substitution rate (SR) of CS for CWP, cost of feed, cost of mortality, and profit or loss accrued for each treatment were used to estimate the economics and benefits of CWP supplementation.

F. Statistical Procedures

All data from field experiments and laboratory analyses were analyzed by SAS (1989) to test the effects of supplementing CS with the different legumes on degradation and passage rates of feeds, nutrient intake, digestion, metabolism, and growth performance in Ethiopian Menz sheep. General Linear model (SAS, 1989) analysis for randomized complete block design was used. Repeated measurements were used to determine treatment effects on nutrient intake, digestion, metabolism,

and growth performance of the sheep. Differences between treatment means were analyzed by least significant difference.

CHAPTER III. RESULTS

A. Characteristics of Corn Stover, Cowpea, and Lablab (Experiments 1 and 2)

1. Nutrient composition

Composition of CS, CWP, and LAB is shown in Tables 3, 4, and 5. Dry matter percentage (Table 3) of CS, CWP, and LAB were 90.9%, 89.2%, and 89.9% respectively. Total N contents of CWP and LAB were 2.5% and 2.3%. Acid detergent insoluble nitrogen of CWP and LAB was 8% and 13% indicating that 92% and 87% of the total N was available, respectively. Neutral detergent fiber of CS was higher than that found in CWP and LAB. Lignin content of CS was 4.6% compared with CWP and LAB that contained 5.5% and 6.8% respectively.

Concentration of macro and trace minerals in CS, CWP, and LAB are shown in Tables 4 and 5. Mineral contents of CWP and LAB were higher than CS except the values for Na and Zn that were lower in the legumes.

Table 3. Nutrient composition of corn stover, cowpea, and lablab hay

Composition	CS	CWP	LAB
Dry matter (%)	90.9	89.2	89.9
Total nitrogen (%)	0.6	2.5	2.3
Gross energy (MJ/g DM)	18.6	18.7	18.9
Acid detergent fiber (%)	46.7	34.7	37.4
Acid detergent insoluble nitrogen (%)	0.2	0.2	0.3
Available nitrogen (%)	0.4	2.3	2.0
Neutral detergent fiber %	80.6	41.5	49.1
Lignin (%)	4.6	5.5	6.8

Table 4. Macro mineral content of corn stover, cowpea, and lablab hay

Item, g/kg DM	CS	CWP	LAB
Calcium	1.5	10.7	11.3
Phosphorus	1.4	6.7	5.3
Magnesium	0.9	2.5	3.0
Sodium	0.09	0.04	0.05
Potassium	8.7	18.7	16.0

Table 5. Trace mineral content of corn stover, cowpea, and lablab hay.

Item, mg/kg	CS	CWP	LAB
Iron	449.9	535.3	496.7
Maganese	41.5	54.8	38.9
Copper	8.9	9.9	17.3
Zinc	35.9	30.9	33.1

2. Degradation kinetics of feeds (Experiment 1)

a. Dry matter degradation

The *in situ* degradation kinetics of DM in CS, CWP, and LAB incubated in sheep fed LAB and CWP as supplements to CS are shown in Table 6. There were significant (P<.01) differences among feeds for rapidly degradable A fraction, rates of degradation, potential degradability, and rumen undegradable DM. Cowpea and LAB had higher (P<.01) rapidly degradable A fractions, rates of degradation, and potential degradable DM compared with CS. Rates of DM degradation of CWP and LAB were more than twice that of CS. Forty-two percent of the DM in CS was undegradable, whereas 18.7% and 17.6% of CWP and LAB were not degraded, respectively

Table 6. Dry matter fractions and kinetics of degradation of corn stover cowpea, and lablab in sheep fed diet A. (Exp. 2)

Item	CS	CWP	LAB	SE
A, %	20.5[a]	38.7[b]	34.7[b]	5.5
B, %	37.5[b]	42.7[b]	48.1[c]	2.2
K_b, %	0.02[a]	0.05[b]	0.06[b]	0.01
Pd, %	58.0[a]	81.4[b]	82.8[b]	2.0
Ed, %	54.1[a]	51.0[a]	45.9[b]	1.6
RUDDM, %	42.0[a]	18.6[b]	17.2[b]	2.4

Means within a row with similar superscripts are not different significantly (P> .05).

A = rapidiy degradable
B = slowly degradable
K_b = average rate of degradation
P_d = potential degradability or A + B
Ed = effective degradability
RUDDM = rumen undegradable dry matter

The effects of supplementation on the rapidly degradable DM fraction of the feeds are shown in Table 7. Treatment C increased the degradation of the rapidly degradable fraction of CS by 44.9%, whereas other treatments (B, D, E, and F) did not have any significant effect (P>.05). Rapidly degradable DM fraction of CWP was not different in treatments A, C, and E. Treatment D increased the DM degradations of rapidiy degradable fraction of CWP by 20.4%. Dry matter degradation of the rapidly degradable fraction of LAB was increased by 28.5% with treatment B, whereas A, C, D, and E did not have any effect. Treatment F showed some tendency of decreasing the DM degradation of the rapidiy degradable A fraction of CWP and LAB 25.6% and 31.1%, respectiveiy.

Influence of supplementation on the slowly degradable B fractions of DM of the feeds are shown in Table 8. Treatment D increased (P<.01) the degradation of

slowly degradable DM fraction of CS from 37.3% to 68%, followed by F with 65.5%. Treatments B, C, D, E, and F increased (P<.05) the degradation of the slowly degradable DM fraction of CS. Treatment F significantly (P<.01) increased the degradation of the slowly degradable DM fraction of CWP and LAB from 42.7% to 53.1 and 33.1% to 43.3%, respectively.

Average corrected *in situ* DM loss at various hours of incubation are shown in Table 9. Washing loss (loss at 0 h) for CS was much less (P<.01) than for CWP and LAB. Maximum DM losses from CS, CWP, and LAB were 64.9%, 82.0%, and 68.8% N , respectively. All the feeds attained their maximal in situ DM loss at 96 h of incubation. Patterns of DM lost from CS, CWP, and LAB during washing and incubation in the rumen are shown in Figure 1.

Table 7. The effect of supplementation on the rapidly degradable DM fractions of corn stover, cowpea, and lablab (Exp. 2)

Treatment	CS	CWP	LAB	SE
		%		
A	20.5[a]	38.7[a]	34.7[a]	5.5
B	15.1[a]	32.9[b]	44.6[b]	8.9
C	29.7[b]	39.1[a]	38.2[a]	2.9
D	16.7[a]	46.6[c]	35.1[a]	8.7
E	21.3[a]	42.7[a]	36.4[a]	6.3
F	17.2[a]	28.8[d]	23.9[c]	3.3

Means within a row with similar superscripts are not different significantly (P>.05).

Table 8. The effects of supplementing the slowly degradable DM fractions of corn stover, cowpea, and lablab hay (Exp. 2)

Treatment	CS	CWP	LAB	SE
		%		
A	37.5[a]	42.7[a]	48.1[a]	2.2
B	54.9[b]	47.5[b]	26.5[b]	2.3
C	52.3[b]	42.1[a]	34.2[c]	2.1
D	68.4[c]	37.7[c]	32.3[c]	2.7
E	60.4[c]	38.7[c]	32.9[c]	2.2
F	65.5[c]	53.1[d]	43.3[d]	2.5

Table 9. Average washing and in situ DM loss at various hour(Exp.2).

Incubation time, h	CS	CWP	LAB	SE
		%		
0[1]	9.4	29.6	35.0	2.1
6	27.7	49.7	47.3	1.6
12	31.2	55.9	53.4	1.2
24	40.8	68.1	60.2	1.3
48	52.7	77.3	65.7	1.2
72	64.3	78.1	66.6	1.2
96	64.9	82.0	68.8	1.1
120	64.5	80.9	68.6	1.1

[1]Percentage of DM lost from feeds during washing of bags.

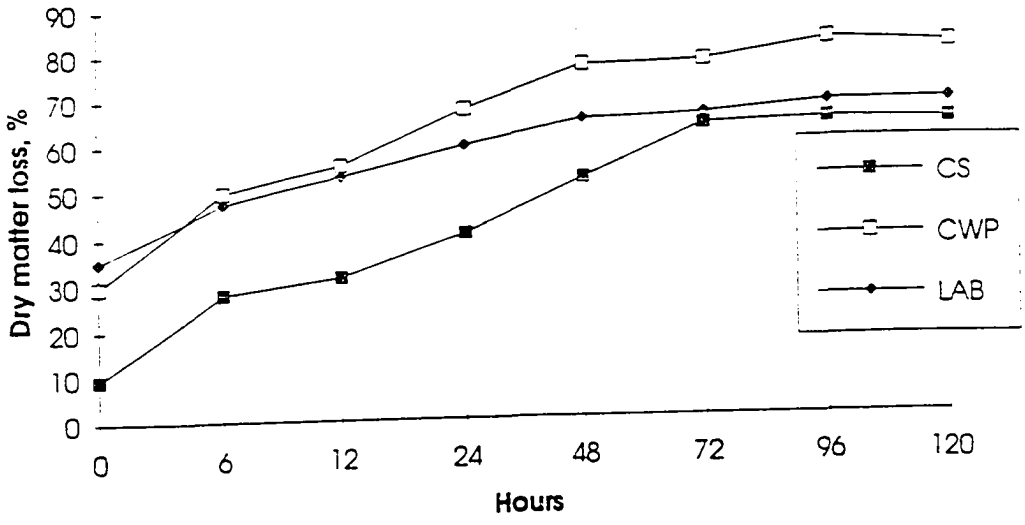

Figure 1. Patterns of DM lost from corn stover, cowpea, and lablab during washing and incubation in the rumen.

b. Nitrogen degradation

Degradation kinetics of N of individual feeds are shown in Table 10. Cowpea had higher (P<.05) slowly degradable N fraction (58.3%) compared with LAB (46.6%) and CS (38.9%). Rates of N degradation of rapidly degradable N, potential degradable N, effective N degradability, and rumen undegradable N were similar (P>.05) for CWP and LAB, but greater (P<.01) than CS. The rate of N degradation of CS was lower (P<.05) than LAB and CWP but percentage of total N degraded in CS increased with supplemented diets. Supplementation increased (P<.01) rapidly degradable and slowly degradable N fractions of all the feeds.

Table 10. Average nitrogen fractions and kinetics of nitrogen degradation of corn stover, cowpea, and lablab in sheep fed diet A (Exp. 2)

Item	CS	CWP	LAB	SE
A[1], %	19.0[a]	26.2[c]	35.4[a]	4.9
B[1], %	38.9[a]	58.3[b]	46.6[c]	4.8
K_b[1], %	0.03[a]	0.07[b]	0.06[b]	0.01
Pd[1], %	57.9[b]	84.5[c]	82.0[c]	8.8
Ed[1], %	37.1[b]	66.6[c]	66.8[c]	10.8
RUDN[2], %	42.1[b]	15.5[c]	18.0[c]	8.8

[1]Same as in Table 6.
[2]Rumen undegradable nitrogen = 100 - (A+B).
Means within a row with similar superscripts are not different significantly (P >.05).

The effects of supplementation on the rapidly degradable N fractions of feeds are shown in Table 11. Treatments C and E increased (P<.01) the rapidly degradable N fraction of CS by 42.2%. Rapidly degradable N fraction of CWP was increased from 19.1% to 39.9% with treatments D, E, and F, whereas LAB increased from 35.4% to 42.1% under treatments C,E and F. Other treatments tended to increase the rapidly degradable N fraction of the feeds, but the improvement was not significant (P>.05).

The slowly degradable N fractions of CS, CWP, and LAB are shown in Table 12. Supplementation did not improve the degradation of slowly degradable N fraction of CS (P>.05). Percentage of slowly degradable N fraction of CS in treatment C and D were lower (P<.01) and negative value was obtained from treatment E. Slowly degradable N fraction of CWP was increased (P<.01) from 58.3% to 68.4% with diet B and up to 68.0% with diet

Table 11. The effect of supplementation on the rapidly degradable N fractions of corn stover, cowpea, and labiab.(Exp. 2)

Treatment	CS	CWP	LAB	SE
		%		
A	19.0[a]	26.2[a]	35.4[a]	4.9
B	14.1[b]	19.8[b]	32.7[a]	5.5
C	16.5[a]	20.7[b]	42.1[b]	7.9
D	13.8[b]	29.7[a]	34.2[a]	6.1
E	17.2[a]	39.9[c]	42.1[b]	6.2
F	14.7[b]	35.4[c]	37.3[a]	6.2

_Means within a column with similar superscripts are not different significantly (P >.05).

The size of the slowly degradable fraction of LAB increased to 50.5% and 67.4% with treatments E and F, respectively. About 15% of N of CWP and LAB escaped to the small intestines and were apparently digested compared with 50% of N of CS.

Average *in situ* and washing N lost from CS, CWP, and LAB are shown in Table 13. Nitrogen losses during washing of unincubated feed sample were similar for CS, CWP, and LAB. Maximum N lost from CS (49.4%) was obtained at 72 h of incubation. Cowpea and LAB reached their maximum N losses of 84.1% and 80.5%, respectively at 96 h post-incubation. Patterns of N lost from feeds during washing and incubation in the rumen are shown in Figure 2.

Table 12. The effects of supplementation on the slowly degradable N fraction of corn stover, cowpea, lablab.(Exp. 2)

Treatment	CS	CWP	LAB	SE
		%		
A	38.9[a]	58.3[a]	46.6[a]	4.8
B	37.2[a]	68.4[b]	36.1[b]	10.5
C	16.2[b]	65.5[b]	40.3[c]	14.2
D	26.3[c]	55.0[a]	45.1[a]	8.4
E	--	41.0[c]	50.5[d]	4.7
F	38.8[a]	68.0[b]	67.4[e]	9.6

Means within a column with similar superscripts are not different significantly (P >.05).

Table 13. Average washing and in situ N loss at various hours Exp. 2)

Incubation time, h	CS	CWP	LAB	SE
		%		
0[1]	32.9	33.8	32.9	0.3
6	32.1	36.9	46.6	4.3
12	32.4	54.3	39.2	6.5
24	32.6	60.2	59.8	9.1
48	45.4	77.3	73.6	10.1
72	49.4	80.8	75.8	9.7
96	49.1	84.1	80.5	11.1
120	49.0	81.6	80.0	10.6

[1]Percentage of N lost from feeds during washing of bags.

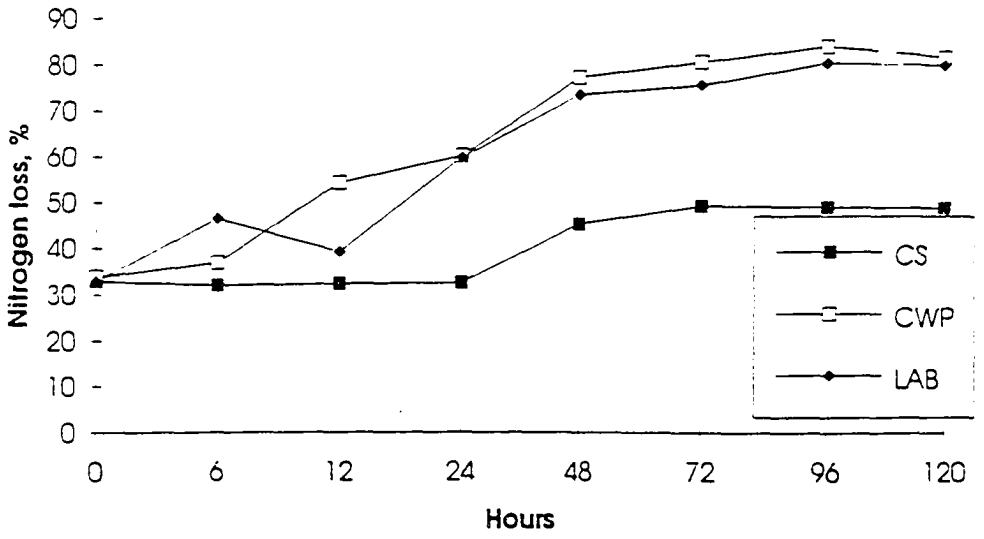

Figure 2. Patterns of N lost from corn stover, cowpea, and lablab during washing and incubation in the rumen.

3. Passage kinetics of feeds (Experiment 2)

Parameters for particulate matter and liquid passage from the rumen and hindgut are shown in Table 14. Passage rates of feed particles from the rumen were higher (P<.01) for CWP and LAB than for CS, but they were similar (P>.05) for the two legumes. Corn stover had greater (P<.01) passage of feed particles from the hindgut compared with CWP and LAB. Liquid passage rates from the rumen and hindgut were similar (P>.05) for all the feeds. Transit times of liquid and

particulate matter were similar (P>.05) among CS, CWP, and LAB. Mean retention times of particulate matter and liquid for CS were significantly longer (P<.01) than CWP and LAB. Cowpea had lower (P<.01) retention time for particulate matter than LAB. Liquid retention times for both supplements did not differ (P>.05).

Table 14. Particulate matter and liquid passage kinetics of mordanted corn stover, cowpea, and lablab fed to Ethiopian Menz sheep (Exp. 2)

Parameter			CS	CWP	LAB	SE
Passage rate, %/h	K_1	P	.023[a]	.031[b]	.029[b]	0.3
		L	.032[a]	.030[a]	.034[a]	0.4
	K_2	P	.054[a]	.013[b]	.012[b]	0.2
		L	.22[a]	.21[a]	.22[a]	1.4
Transit time, h		P	10.9[a]	9.3[a]	8.7[a]	0.4
		L	8.4[a]	8.1[a]	7.5[a]	0.7
Mean retention time, h		P	73.1[a]	44.9[b]	60.2[c]	0.3
		L	44.7[a]	30.2[b]	33.5[b]	4.4

Means within a row with similar superscripts are not different significantly (P >.05).
K_1 = passage from the rumen.
K_2 = passage from the hindgut.
P = particulate matter.
L = liquid.

B. The Effects of Supplementation on Intake, Digestion, and Metabolism of Nutrients (Experiments 3 and 4)

1. Nutrient intake

Average daily intake of DM, NDF, N, and GE are shown in Tables 15 and 16. All the CWP and LAB supplements, which were fed separately and in combination, were consumed completely. Intake of DM, NDF, N, and GE were increased (P<.01) by supplementation with CWP and LAB as shown in Table 15 (Experiment 3). No

significant differences (P>.05) were observed for the intake of DM, NDF, N, and GE among CWP and LAB supplemented diets, except for treatment C which was lower (P<.05) for the intake of DM and NDF. Amounts of CS substituted were similar (P>.05) for all the supplemented diets except treatment C which was higher.

The effects of feeding increasing amounts of CWP (Exp. 4) on nutrient intake are given in Table 16. Supplemented diets had greater (P>.01) nutrient intake compared with non-supplemented CS. Total DM, NDF, N, and GE intake increased linearly (P<.01) with CWP supplementation whereas CS intake decreased with CWP addition to the diets. Intake of CS at CWP supplementation of 267.5 and 397.1 g/d were similar (P>.05). Thirty-five percent of the CS fed at the maximum level of CWP supplementation was replaced with CWP.

2. Apparent digestibility

The effects of supplementation on apparent digestibility of DM, NDF, N, and GE are given in Tables 17 and 18. Treatments C, D, E, and F had higher (P<.01) DM digestibility compared with A and B (Table 17). Digestibility of NDF was higher (P<.01) for treatment B than for the other diets. Supplementation increased the digestibility of N and GE compared with non-supplemented diet. Diet F which contained CWP as a sole supplement had greater (P<.05) percentage of digestible DM, N, and GE compared with treatment B containing LAB alone. Treatment D which contained equal quantities of CWP and LAB did not show any significant increase in the digestibility of nutrients.

Table 15. Average daily nutrient intake of Ethiopian Menz sheep fed corn stover supplemented with cowpea or lablab hay separately or in combinations (Exp. 3)

Daily intake	A	B	C	D	E	F	SE[1]
DM, g/d	515.9[a]	730.7[b]	676.5[c]	725.3[b]	731.5[b]	696.7[b]	17.3
CS, g/d	515.9[a]	447.8[b]	394.4[c]	442.8[b]	450.4[b]	416.3[b]	17.5
CWP or LAB, g/d	-	282.9	282.1	282.5	281.1	280.4	0.4
CS substituted,	-	13.2[a]	23.6[b]	14.2[a]	12.6[a]	19.3[b]	16.8
NDF[2], g/d	396.6[a]	480.5[b]	424.1[c]	461.0[b]	470.9[b]	434.8[b]	15.1
Nitrogen, g/d	3.1[a]	9.1[b]	9.2[b]	9.2[b]	9.2[b]	9.6[b]	1.5
GE[3], MJ/d	9.6[a]	13.6[b]	12.6[b]	13.5[b]	13.6[b]	12.9[b]	0.6

Means within a row with similar superscripts are not different significantly (P > .05).
[1]Standard error of treatment means
[2]Neutral detergent fiber
[3]Gross energy intake

Table 16. Average daily nutrient intake of Ethiopian Menz sheep fed corn stover and supplemented with graded levels of cowpea (Exp. 4)

Daily intake	C0	C1	C2	C3	C4	SE
Total DM, g/d	420.4[a]	475.5[b]	577.1[c]	707.2[d]	797.4[e]	70.2
CS, g/d	420.4[a]	341.6[b]	309.6[c]	310.1[c]	272.9[c]	24.8
CWP, g/d	-	133.9[a]	267.5[b]	397.1[c]	524.5[d]	92.8
CS substituted, (%)	-	19.7[a]	26.4[b]	26.4[b]	35.1[c]	5.9
NDF, g/d	339.0[a]	330.9[a]	378.3[b]	414.7[c]	437.7[d]	20.8
N, g/d	2.5[a]	5.3[b]	8.5[c]	11.8[d]	14.7[d]	2.2
GE, MJ/d	7.8[a]	8.8[a]	10.7[b]	13.0[c]	14.8[d]	1.7

Means within row with the same superscript are not different significantly (P > .05).

The effects of supplementing increasing quantities of CWP to CS (Exp. 4) on the digestibility of DM, NDF, N, and GE are shown in Table 18. Digestibility of DM increased (P<.01) with supplementation of CWP. Digestibility of NDF was not improved (P>.01) by feeding increasing levels of CWP. Digestible N and GE were higher (P<.05) for supplemented diets compared to CS fed alone.

Estimates of rates of DM and NDF intake, passage, and digestion are shown in Table 19. The effect of supplementation was variable among the treatments for the different parameters estimated. Rates of DM intake and digestion were similar (P>.05) for treatments B and D, but higher (P<.05) than treatments A, C, E, and F. Estimated rate of NDF intake of treatments B and D were higher (P<.01) than A, C, E, and F. Rates of passage of NDF and DM were increased (P<.01) for all the supplemented diets. Rates of digestion of NDF were higher (P<.01) in diets B, C, and D, but lower for diets A, E, and F.

3. Metabolism in the rumen

The effects of supplementation on ruminal fluid pH, NH_3-N, VFA, N retention, and microbial N supply are shown in Tables 20 to 23. Ruminal fluid pH (Table 20) for all the treatments ranged from 6.1 - 6.9 with no significant difference (P>.05) among diets. Supplementing CWP once or twice daily (Table 21) did not have any effect on rumen pH. Ruminal pH fluctuated after feeding CWP, but remained above 6.7 during the 10 h of observation after feeding. Time after feeding was one of the major factors that influenced (P<.01) rumen pH.

Table 17. Digestion of nutrients in Ethiopian Menz sheep fed corn stover supplemented with cowpea and lablab separately or in combinations (Exp. 3)

Digestibility	A	B	C	D	E	F	SE
Dry matter, %	50^{a}	49^{a}	55^{b}	54^{b}	57^{b}	55^{b}	1.2
Neutral detergent fiber, %	49^{a}	57^{b}	50^{a}	51^{a}	54^{a}	50^{a}	2.1
Nitrogen, %	-2^{a}	43^{b}	56^{c}	48^{b}	50^{b}	56^{c}	0.8
DE, %	35^{a}	53^{b}	60^{b}	61^{b}	61^{b}	58^{b}	0.9

Means within a row with similar superscripts are not different significantly (P >.05).

Table 18. Digestion of nutrients in Ethiopian Menz lambs fed corn stover supplemented with graded levels of cowpea.(Exp. 4)

Digestibility	C0	C1	C2	C3	C4	SE
Dry matter, %	48^{a}	52^{a}	57^{b}	57^{b}	62^{c}	0.1
Neutral detergent fiber, %	59^{a}	60^{a}	59^{a}	57^{a}	62^{a}	0.1
Nitrogen, %	-7^{a}	52^{b}	52^{b}	56^{b}	58^{b}	0.3
DE, %	53^{a}	72^{b}	71^{b}	72^{b}	71^{b}	0.9

Means within a row with similar superscripts are not different significantly (P >.05).

The effects of supplementing CS with CWP and LAB on NH_3-N concentrations and maintenance are shown in Table 22. Ammonia nitrogen concentrations for supplemented diets were higher ($P<.01$) than CS alone. Comparisons of treatments showed that treatments C, D, and F had higher ($P<.01$) NH_3-N concentrations than B and E. Maximal concentrations of NH_3-N were sustained for about 1 to 3 h after feeding, but began to decline thereafter and remained low during the 10 h of observation. Minimum concentrations of NH_3-N for CS was 0.7 mg/l, whereas minimal concentrations for supplemented diets ranged from 3.6 to 16.7 mg/l.

The influence of supplementing increasing amounts of CWP once or twice daily on NH_3-N concentration are shown in Table 23. Average NH_3-N concentrations for treatments C2, C3, and C4 were higher ($P<.01$) than diets C0 and C1. The maximum concentration of NH_3-N was observed within 2 to 3 h post-feeding. Treatments C2, C3, and C4 which received CWP twice daily had higher NH_3-N concentration compared with feeding the CWP supplement once a day. Lambs supplemented with CWP twice daily maintained a minimum NH_3-N concentrations of 115.4 -135.8 mg/l compared with those fed once daily that had minimum concentrations of 79.7 - 101.0 mg/l for 3 to 10 h of observation. Frequency of supplementation and time after feeding significantly ($P<.01$) influenced rumen NH_3-N concentrations. Average ammonia N concentrations observed at 0 h and within 1 to 10 h post-feeding for lambs fed once and twice daily across treatments are shown in Figures 3 and 4.

Table 19. Digestion kinetics of DM and NDF estimated from daily feed intake, fecal flow, and rumen volume (Exp. 2)

Estimates	A	B	C	D	E	F	SE
Kinetics of DM digestion,							
Rate of intake, g/h	33.8[a]	52.9[b]	36.6[a]	53.8[b]	39.7[a]	41.9[c]	3.4
Rate of passage, g/h	14.5[a]	17.5[b]	16.5[b]	17.8[b]	16.3[b]	20.1[c]	0.7
Rate of digestion, g/h	19.3[a]	35.4[b]	20.1[a]	36.0[b]	23.4[a]	21.8[a]	3.1
Kinetics of NDF digestion							
Rate of intake, g/h	29.4[a]	42.1[b]	27.5[a]	42.3[b]	30.2[a]	31.3[a]	2.7
Rate of passage, g/h	15.7[a]	20.2[b]	18.8[b]	20.6[b]	18.7[b]	22.8[c]	0.9
Rate of digestion, g/h	13.7[a]	21.9[b]	18.7[b]	21.7[b]	11.5[a]	8.5[a]	2.4

Rate of digestion = rate of intake - rate of passage.
Means within a row with similar superscripts are not different significantly (P >.05).

Table 20. The effects of supplementing corn stover with cowpea and lablab separately and in combinations on ruminal fluid pH[1] (Exp. 3)

Item	A	B	C	D	E	F	SE
Average	6.4	6.5	6.6	6.4	6.5	6.5	0.1
Maximum	6.7	6.8	6.9	6.8	6.8	6.8	0.1
Minimum	6.1	6.2	6.3	6.1	6.2	6.3	0.1

[1]Ruminal fluid pH across treatments were not different significantly (P >.05).

Table 21. The effects of once and twice[1] daily cowpea supplementation on ruminal fluid pH (Exp. 4)

	Hours post-feeding								
Feeding method	0	1	2	3	5	6	7	10	SE
1X	7.2	6.9	7.1	6.9	6.9	6.9	7.0	6.7	0.2
2X	7.1	6.8	6.9	6.9	6.6	6.9	6. 9	6.9	0.1

[1]Once and twice daily supplementation did not change rumen fluid pH (P >.05).

Table 22. The effects of supplementing corn stover with cowpea and lablab separately and in combination on the concentrations of ruminal fluid NH3-N (Exp. 3)

Item	A	B	C	D	E	F	SE
Average	44.2^{a}	114.8^{b}	162.9^{c}	131.1^{d}	116.4^{b}	144.0^{d}	9.3
Maximum	56.0	139.6	162.9	131.1	116.4	144.0	16.9
Hours at maximum	1	1	1	3	3	2	nd
Minimum	0.7	7.8	16.2	8.2	3.6	16.7	2.6

Means within a row with similar superscripts are not different significantly (P >.05).
nd = was not determined.

Table 23. Influence of supplementing corn stover with graded levels of cowpea[1] once or twice daily on NH_3-N concentrations (Exp. 4)

Item	C0	C1	C2	C3	C4	SE
			mg/l			
Average	104.9a	108.7[a]	132.9[b]	133.6[b]	134.5[b]	8.4
1X	99.5a	115.1[a]	125.9[b]	126.8[b]	106.1[a]	9.9
2X	110.3a	102.4[a]	140.1[b]	140.6[b]	162.9[c]	8.4
Maximum	209.6	250.0	298.3	281.2	332.4	20.4
Hours at maximum	2	3	3	3	3	
Minimum	6.1	34.1	59.7	51.1	59.7	10.2

[1]The same quantity of CWP was fed either in one part or two parts daily.
Means within a row with similar superscripts are not different significantly (P >.05).

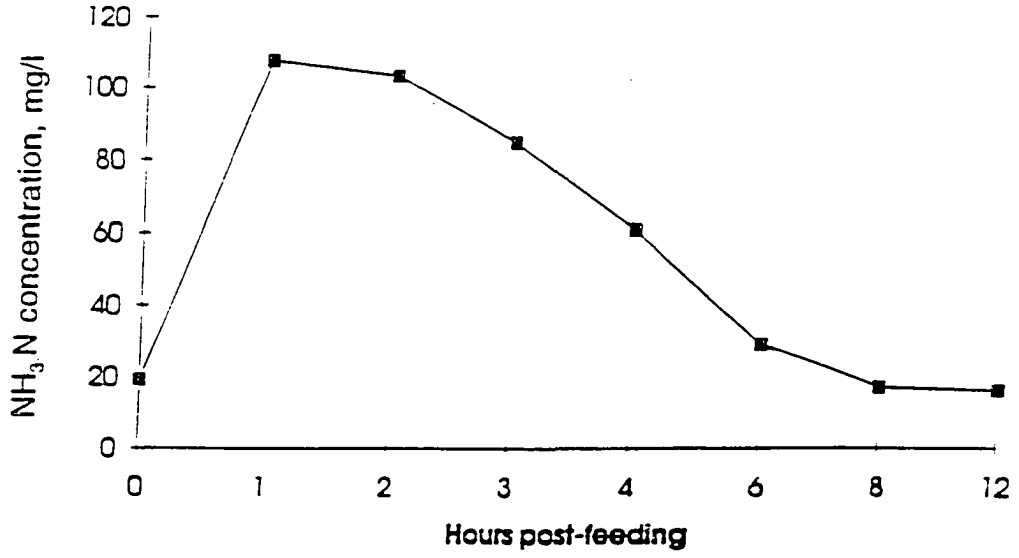

Figure 3. The influence of supplementing CS with CWP and LAB separetly or in combination once daily on average ruminal ammonia nitrogen concentrations across treatments (Experiment 3).

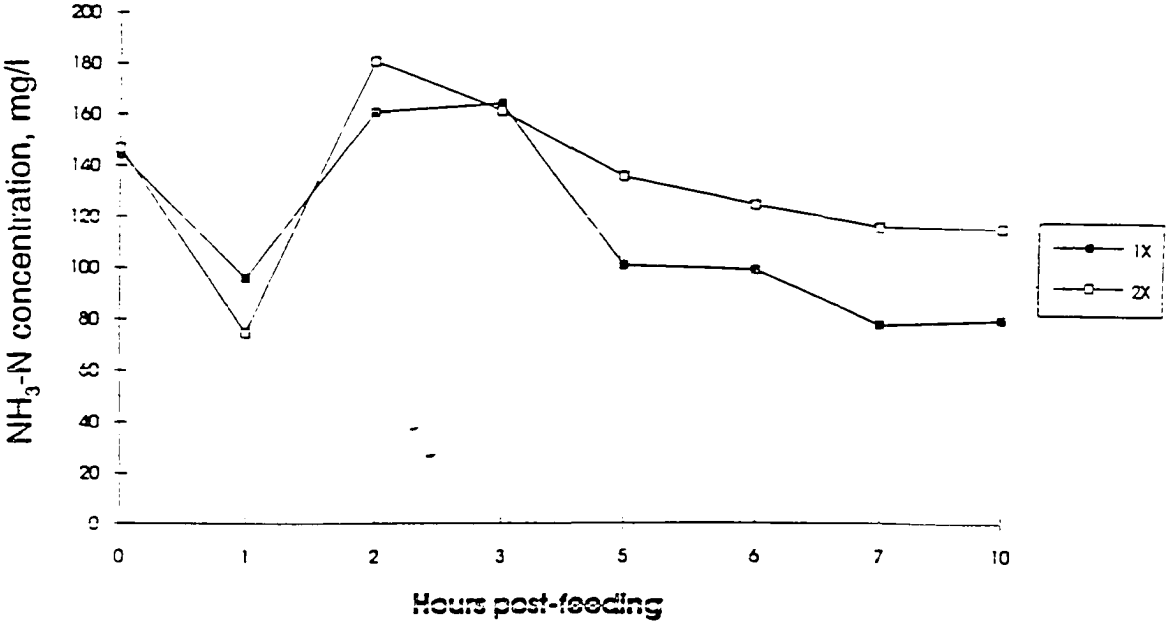

Figure 4. The influence of supplementing CS with graded levels of CWP once and twice daily on average ruminal ammonia nitrogen concentrations across treatments (Experiment 4).

a. Volatile fatty acids

Concentrations of VFA obtained from Experiment 3 are shown in Table 24. Total VFA concentrations for supplemented diets were higher (P<.05) than for non-supplemented diet. Highest VFA concentrations were obtained from diet D compared to the other supplemented diets. Concentrations of acetic and butyric acids increased (P<.01) by supplementation. Propionic acid concentrations were increased (P<.05) only for treatment D and F. Time of sampling after feeding had significant (P<.01) effects on total and individual VFA concentrations (Figure 5).

Isoacids accounted for about 2 % of the total VFA concentration, but their individual concentrations were not increased (P>.05) by supplementation. Time of sample collection did not change (P>.05) the concentrations of either isobutyrate, valerate, or isovalerate.

b. Nitrogen retention and microbial N supply

Nitrogen intake, retained, and microbial N supply from supplementing increasing quantities of CWP are shown in Table 25. Supplementation significantly (P<.01) increased nitrogen retention. Feeding CS alone resulted in negative N balance compared to supplemented diets. Microbial N supply was greater (P<.01) with supplemented diets compared with non-supplemented CS diet. There was a linear increase in N retention and microbial N supply with daily N intake.

Table 24. The effects of supplementing corn stover with cowpea or lablab on ruminal fluid VFA (Exp. 3)

Concentrations	A	B	C	D	E	F	SE
				mmol/l			
Total VFA	94.5[a]	101.7[b]	116.6[c]	127.8[a]	109.9[b]	117.7[c]	4.4a
Total isoacids	1.4[a]	1.8[a]	2.3[b]	2.4[b]	2.4[b]	2.1[a]	0.1
VFA							
Acetate	70.2[a]	75.5[b]	84.3[c]	95.5[d]	82.4[c]	86.5[c]	3.6
Propionate	16.9[a]	17.4[a]	17.8[a]	21.3[b]	17.7[a]	20.3[b]	0.7
Butyrate	6.0[a]	7.2[b]	7.7[b]	8.7[c]	7.5[b]	8.9[c]	0.4
Isoacids[1]							
Isobutyrate	0.2	0.2	0.3	0.3	0.7	0.2	0.1
Valerate	0.6	0.9	1.1	1.2	1.0	1.1	0.1
Isovalerate	0.6	0.7	0.9	0.9	0.7	0.8	0.1

Means within a row with similar superscripts are not different significantly ($p > .05$).

[1]Individual isoacid concentrations were not affected by supplementation ($P > .05$).

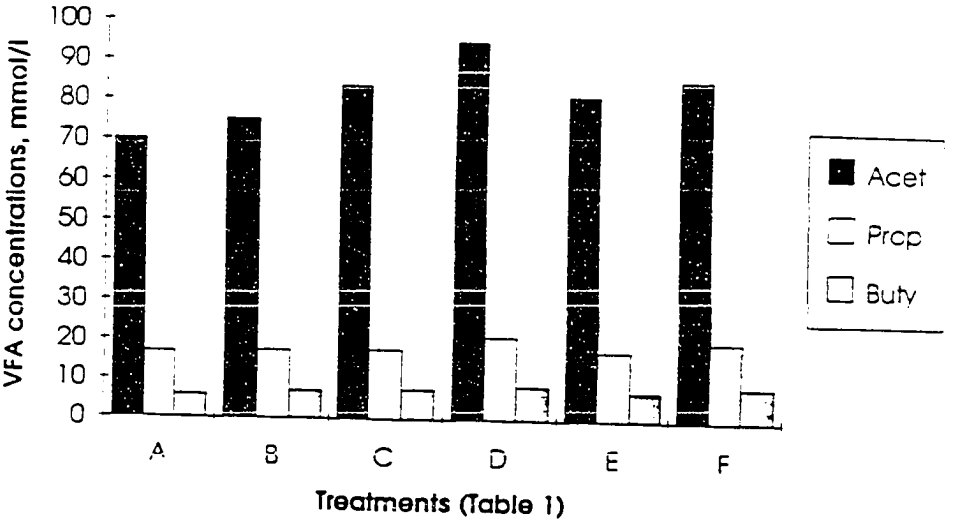

Figure 5. Concentrations of individual volatile fatty acids as influenced by supplementating CWP and LAB separately and in combinations to CS (Experiment 3).

C. Growth Performance of Lambs and Economics of Cowpea Supplementation (Experiment 5)

1. Growth performance of lambs

The effects of feeding increasing levels of CWP on the performance of growing lambs are shown in Table 26. Total DM intake, ADG, and FCE were increased ($P<.01$) by CWP supplementation. Treatments containing CS alone had negative ADG and FCE. Percent substitution of CS for CWP were similar ($P>.05$) for C2 and C3. Highest ADG was obtained at CWP supplementation of 524.5 g/d (C4) but 35.1% of CS was was replaced by CWP. Weight gain per weight of feed

consumed (FCE) was higher at maximal CWP supplementation. Lowest percentage of substitution rate was obtained for treatment C1 containing the least level of CWP.

The effects of once and twice daily supplementation of CWP on ADG for each treatment are shown in Table 27. Lambs supplemented twice daily had hogher ($P<.05$) ADG compared with those fed once daily in treatments C3 and C4.

2. Economics of using graded levels of cowpea

Costs, economic returns, net profits, and value of CWP when fed as supplement to CS are shown in Tables 28, 29, and 30. Results indicated that supplementation of CWP to CS was economical with reference to preventing the death and weight loss of lambs, and higher incremental returns, and increased value of CWP. Three lambs from CS fed animals (Table 29) died during the 4th week of the growth trial and this represented 50% of the six sheep in the treatment. Death loss was the highest cost of production, followed by the initial purchase price of the lambs. Lowest gross value was obtained from non-supplemented lambs, whereas highest amount was observed at the highest level of CWP supplementation (C4).

There was a loss of $68.78 (Table 30) when CS was fed alone. Losses declined from $68.76 to $13.09 at the lowest level of CWP supplementation (C1). Reduction in profit improved with increasing CWP supplementation until a profit of $1.69 was obtained when the highest level of CWP was fed. Incremental returns

from CWP was $55.67 at the lowest level of CWP supplementation, but declined with increasing CWP supplementation up to C3. Incremental returns from CWP increased from $1.89 (C3) to $6.37 at the highest level of CWP (C4) supplementation. Incremental value of CWP ($/kg) similarly declined from $4.95 (C1) to $0.17 (C3) with CWP feeding but increased $0.17 to $0.60 at the highest level of CWP supplementation (C4).

Table 25. The effects of supplementing corn stover with graded level of cowpea on N retention and microbial N supply[1] (Exp. 4)

Measurement	C0	C1	C2	C3	C4	SE
N intake, g/d	2.4	5.2	8.4	11.5	14.5	2.2
N retention, g/d	-1.8	0.2	1.9	3.1	4.8	1.1
Microbial N, g/d	0.5	1.2	2.3	3.5	4.6	0.7

[1]Microbial N supply was estimated from urinary purine derivatives.
Means within a row with similar superscripts are not different significantly (P >.05).

Table 26. The effects of supplementing corn stover with graded levels of cowpea on the performance of Ethiopian Menz lambs (Exp. 5)

Item	C0	C1	C2	C3	C4	SE
Total DM intake, g/d	420.4^{a}	475.5^{b}	577.1^{c}	707.2^{d}	797.4e	70.2
Average gain, g/d	-17.8^{a}	10.0^{b}	25.2^{d}	32.2^{d}	46.5^{e}	6.3
Feed conversion, g gain/g feed	-0.04	0.02	0.04	0.05	0.06	0.01

Means in a row with similar superscripts are not different significantly (P >.05)

Table 27.. The effects of once and twice daily supplementation on average daily weight gain of Ethiopian Menz lambs (Exp. 5)

Feeding method	C0	C1	C2	C3	C4	SE
			g/d			
1X	-18.0^{a}	9.8^{a}	25.8^{a}	30.5^{a}	44.0^{a}	10.6
2X	-17.6^{a}	10.3^{a}	24.6^{a}	33.4^{a}	49.1^{b}	11.3

Means in a column with similar superscripts are not differently significantly (P >.05).

Table 28. Costs of suplementing corn stover with graded levels of cowpea and fed to Ethiopian Menz lambs (Exp. 5).

Item	C0	C1	C2	C3	C4
Period, days	84	84	84	84	84
Lambs/treat	6	6	6	6	6
Cost/lamb, $	17.00	17.00	17.00	17.00	17.00
No. of death[1]	3	-	-	-	-
Cost of mortality, $	51.00	-	-	-	-
Cost of live lambs, $	51.00	102.00	102.00	102.00	102.00
CS intake live lambs, kg	105.94	172.16	156.03	156.29	137.54
CS intake dead lambs, kg	33.63	-	-	-	-
Total cost of CS, $	9.77	12.05	10.92	10.94	9.62
CWP intake live lambs, kg	-	11.24	22.47	33.35	44.05
CWP intake dead lambs, kg	-	-	-	-	-
Total cost of CWP, $	-	1.12	2.24	3.33	4.40
Total cost of labor, $	4.20	4.20	4.20	4.20	4.20
TOTAL COSTS, $	115.97	119.37	119.36	120.47	120.23

1Death of lambs occurred during the 26th and 28th day of the study. Corn stover and CWP intake were calculated based on the number of days the lambs were in the growth study. Corn stover (CS) price, $0.07/kg.
Cowpea (CWP) price, $0.10/kg. Lambs price, $17.00 for 20kk live wt. = $0.85/kg.
Labor $1.00/ 8-hour work day, two hours to care for 30 lambs = $0.25/day.
Labor cost/ lambs/day = $0.0083.

Table 29. Economic returns of supplementing corn stover with graded levels of cowpea and fed to Ethiopian Menz lambs (Exp. 5)

Items	C0	C1	C2	C3	C4
Economic returns					
Total wt . change, kg	-4.45	5.04	12.70	16.22	23.43
Price of wt. change, $	-3.28	4.28	10.79	13.79	19.92
Price of live lambs, $	51.00	102.00	102.00	102.00	102.00
Gross value, $	47.21	106.24	112.79	115.79	121.92

Table 30. Net profit and value of cowpea when supplemented to corn stover and fed to Ethiopian Menz lambs (Exp. 5)

Item	C0	C1	C2	C3	C4
Gross value, $	47.21	106.24	112.79	115.79	121.92
Total costs, $	115.97	119.37	119.36	120.47	120.23
Profit, $	-68.76	-13.09	-6.57	-4.68	1.69
Incremental return from CWP[1], $	-	55.67	6.52	1.89	6.37
Incremental value of CWP[2], $/kg	-	4.95	0.58	0.17	0.60

[1]Incremental return from CWP = e.g. -68.76 - (-13.09); -13.09 - (-6.57), etc.
[2]Incremental value of CWP = e.g. -68.76 - (-13.09)/11.24*.
*CWP intake under each treatment.

CHAPTER IV. DISCUSSION

A. Characteristics of Corn Stover, Cowpea, and Lablab

The percentages of ADIN found in CWP and LAB were 8% and 13% (Table 3) suggesting that 92% and 87% of the total N respectively was available. Available N of the legumes was equivalent to 12.5% and 14% crude protein. The Food and Agricultural Organization (FAO, 1988) estimated that many tropical legumes contained 12% to 24% crude protein. The corn stover used in this study contained 0.6% N of which 0.3% was ADIN indicating that 50% of the total N was not available.

The nutrient requirements of livestock reared in the tropics have not been as accurately described as those in temperate regions. However, the most limiting nutrients for ruminants that subsist on fibrous forages are N, soluble sugars, and minerals. Under most tropical conditions lambs remain with the ewe until the next gestation and therefore a high percentage of the protein requirement is met from milk consumed during the nursing period (Keari, 1982). Chiou and Jordan (1973) studied the nutrient requirements of the Awassi sheep, and estimated that under tropical conditions, sheep with an average body weight of 25 to 39 kg required between 62.5 to 75 g digestible crude protein per day. National Research Council (NRC, 1985) estimated crude protein contents of 12 to 15% to be adequate for finishing lambs to gain up to 200 g/d. These values were within the same range as the percentages of crude protein found in CWP and LAB in the studies for this

dissertation which suggests that the legume supplements were capable of meeting the crude protein requirements of the sheep.

Lignin content of CWP and LAB were higher than in CS (Table 3). The higher lignin in LAB and CWP was consistent with the report of Ndlovu (1992). Macro and trace minerals were higher in CWP and LAB compared with CS (Table 3 and 4). The concentrations of Ca and P in CWP and LAB obtained from this study were 10.5 and 6.5 g/kg DM, respectively. This observation was similar to the results of Mackie and Therion (1984), but did not confirm the reports of Kabaija and Little (1987) which indicated that tropical legumes contained lower Ca and P. The amounts of Ca and P recommended by Jurgens (1988) for sheep of moderate growth, range from 2 to 8 and 2 to 4 g/kg DM, respectively. These values were also lower than the amounts of Ca and P obtained from the legumes in this study. Level of fertilizer used in the soil, stage of maturity, and the parts of the plants that were analyzed could have been responsible for the discrepancy between the reports cited and our observations.

Supplementation of low quality feed with N is expected to increase ruminal degradation of fiber which the small intestine has a limited capacity to digest. Feed intake and post-ruminal supply of N are increased as a result of increased rate of ruminal fermentation. Supplementation of CS with a mixture of CWP and LAB increased the degradation of DM and N in the feeds (Table 6). The degradation rates (K_b) of DM and N in CWP and LAB were twice that of CS. A maximum of 82% and 68% of DM in CWP and LAB respectively were degraded compared with

64% of CS. The higher degradation rates of CWP and LAB could be related to the fragility of the cell walls of legumes (Akin, 1982) compared with CS. Degradation of slowly degradable DM and N fractions of the feeds were increased by supplementation, but the effects were more pronounced on the slowly degradable DM fraction of CS. The degradation of the slowly degradable portion of feed is usually dependent on an efficient rumen environment and the length of incubation time. The higher extent of DM degradation in CS indicated that the rumen environment was improved by supplementation with CWP and LAB. Inherently, CWP and LAB have higher degradation rates and that were not affected by changes in conditions in the rumen compared with CS that required an optimal rumen environment for digestion of fiber. More than 80% of the N in CWP and LAB was degraded at 96 h of incubation. Nitrogen degraded from CWP and LAB was a reflection of the high amounts of available N and higher rates of degradation of both legumes. Based on calculated ADIN, 50% of the N in CS was apparently available, which was nearly the same as the maximum percentage of rumen degradable N observed. Rates and extent of N and DM degradation in CS, CWP, and LAB were time dependent (Table 9 and 13). Rates of degradation (% degraded/h) were faster from 24 to 48 h, but declined gradually with a further increase in incubation time. The negative value observed from the slowly degradable fraction N of CS could be associated with the attachment of bacteria to the fibrous feed particles as observed by Hvelplund (1989) when high fibrous hay was studied.

The passage rates of the feeds from the rumen were influenced by their degradation rates and the form in which they were fed (Table 14). Corn stover was partially chopped, contained 80.6% NDF/kg DM, and had a slower degradation rate compared with CWP and LAB. The slower passage rate of CS from the rumen could be associated with the proportion and length of its fiber. Fermentation gasses entrapped in the fiber matrix of unprocessed feed also reduces the passage rate from the rumen and results in an increased retention time of the solid particles. The degradation rates of CWP and LAB were higher than CS and probably explains the faster rate of passage of CWP and LAB from the rumen.

B. The Effects of Supplementation on Intake, Digestion, and Metabolism of Nutrients

The increased intake of DM, NDF, N, and GE was associated with an increased concentration of these nutrients when CWP and LAB were added to the diets (Table 15 and 16). A similar trend was observed when more CWP was fed in Experiment 4. The influence of N concentration was significant ($P<.05$) for apparent digestibility of DM and NDF when graded levels of CWP were fed but varied among the diets containing mixtures of CWP and LAB fed at a fixed level. Nitrogen intake from diets containing graded levels of CWP increased from 2.5 to 14.7 g/d whereas diets with the mixture of CWP and LAB had an average N intake of 9.2 g/d. Dry matter, NDF, N, and GE digestibility were likewise higher with dietary treatments containing the graded level of CWP than those with constant amounts

or mixtures of CWP and LAB. Comparatively, the digestion of nutrients in diets containing the graded levels of CWP did not increase until daily N intake was over 8.5 g/d. The higher rates of degradation and passage of CWP could partially explain the increase in nutrient digestion with increasing quantities of CWP supplementation. There were no direct relationships between the digestion of DM and NDF measured and the rates estimated (Table 19) from feed intake, rumen pool size and daily fecal excretion.

Lambs supplemented twice daily had higher ($P<.01$) intake of DM, CS, and NDF and lower substitution rate of CS. Lambs supplemented once or twice were given the same quantity of CWP and the nutrient composition of the diets fed were the same. Therefore the higher CS intake and lower substitution rates could not be attributed to the nutrient content of the diet but perhaps was due to the method by which the supplements were offered. The supplements were given first before the lower quality basal CS which gave the lambs a more opportunity to get most of their DM requirements from the legumes. The increase in CS intake with frequency of supplementation was similar to the observation of Istasse et al. (1986).

The ruminal pH obtained from supplemented and non-supplemented diets were in the range of 6.1 to 6.9 (Table 20) and were typical of a rumen environment of a forage fed animal (Owens and Goetsch, 1988). Time after feeding was the major factor that influenced the level of rumen pH, which fluctuated within the range of 6.1 to 6.9 throughout the 10 h of observation. The pattern of saliva flow

after feeding could be responsible for the fluctuation in rumen pH. Saliva flow increases with feeding and rumination and rumen pH sometimes decreases slightly after feeding (Harold, 1993). The average pH observed in this study would have provided a satisfactory rumen environment to maintain microbial cellulolytic activity.

Perdok et al. (1988) suggested that rumen NH_3-N concentrations below 50 mg/l limited the utilization of low quality forages. The level of NH_3-N required to maximize fiber digestion is not presently known. The maximum NH_3-N concentration in Experiment 3 obtained from diets containing only CS was 56 mg/l and decreased within 1 h post-feeding to 0.7 mg/l. Concentration of NH_3-N of 50 to 200 mg/l recommended by Satter and Slyter (1974) were higher than the value obtained from diets containing mixtures of CWP and LAB after 3 h post-feeding. Supplementation of CS with a mixture of CWP and LAB increased the average NH_3-N concentration from 44.2 to 162.9 mg/l. Increased degradation of DM and N in CS and greater NH_3-N concentrations when CS was supplemented with CWP and LAB as protein sources suggested that the major limiting nutrient in the diet was N. The higher concentrations of NH_3-N obtained from supplemented diets also indicated that the addition of CWP and LAB created a functional cellulolytic microbial population. Starvation of rumen microbes for ammonia at lower NH_3-N concentrations could be responsible for the lower intake and digestion of nutrients with diets containing CS alone.

Supplementation of CWP twice daily at an interval of 4 h resulted in maintaining minimum NH_3-N concentrations within the range of 115.4 to 135.8

mg/l compared with sheep fed once daily that had concentrations ranging from 79.7 to 101.0 mg/l from 3 to 10 h post-feeding. The higher feed intake observed with lambs supplemented twice daily was consistent with the suggestion of Preston and Leng (1987) that feed intake could be improved by increasing the frequency of supplementation which resulted in maintaining NH_3-N concentrations above 50 mg/l for most of the day.

A higher concentration of acetate relative to propionate and butyrate was obtained from all the diets. The higher concentration of acetic acid was consistent with the reports by Orskov and Ryle (1990) that poorer quality and mature roughage yielded greater acetic acid relative to the other VFA. Supplementation did not increase the concentrations of isobutyric, isovaleric, and valeric acids. The higher amounts of isoacids which are produced by rumen microbes through the process of sequential growth and lysis of other microorganisms (Miura et al, 1980) could be responsible.

Nitrogen intake and retention increased linearly with CWP supplementation. Increased daily N intake with CWP supplementation also resulted in a linear increase in microbial N supply to the small intestine. Improvements in N retention and microbial N supply were associated with a higher N content and greater rate of degradation of the N fractions in CWP compared with CS. Lambs fed CS had lower N intake, less microbial N supply, and negative N retention compared with the supplemented groups. The negative N retention and lower microbial N supply implies that the lower N and higher fiber content of CS limited the quantity of

amino acids absorbed from the small intestine.

C. Growth Performance of Lambs and Economics of Cowpea Supplementation

Supplementation with CWP increased ADG of lambs linearly (Table 20). Substitution rate of CWP for CS ranged from 19.7% for the lowest level of CWP supplementation to 35.1% when the highest level was fed. Increased ADG of lambs supplemented with CWP was associated with improved rumen environment and increased rumen metabolites concentrations which lead to an overall improvement in feed utilization. Lambs fed CS alone lost an average of 17.8 g daily and three animals died during the 4th week of the growth trial. The percentage of N apparently available from CS perhaps was inadequate to maintain the lambs that had previously been on a low plane of nutrition.

Non-supplemented lambs had a net loss of $68.76. In addition to the prevention of death loss among lambs, an increased body weight gain, net decline in losses from $68.76 to $13.09 and as low as $4.68 were obtained with CWP supplementation. A net profit of $1.69 ($1.69/6 = $0.28/lamb) was obtained at the highest level of CWP supplementation. Incremental returns and value of CWP were $55.67 and $4.95, respectively, but declined with increasing CWP supplementation.

However, the level of CWP supplementation that can be used by an individual farmer must take into consideration the alternative use of CWP other than for feeding and the availability of land to grow the legume. The amount of land that

can be set aside from the cultivation of other food crops is critical. If the availability of land is a limiting factor, than supplementation at the lowest level (C1) is recommended to prevent the death of animals as observed from this study. At the lowest level of 133.1 g/d, the incremental returns to CWP and value of CWP were high enough to compensate for the land that will be set aside to cultivate the legume especially for period of limited feed availability. Usually in the bean (cowpea, pigeon peas, chicken peas, etc) consuming regions of SSA, these legumes are grown primarily for the pulses which are used as food for humans. Under the traditional cropping system with little on capital input legumes are relatively cheap to grow and the residues from the harvest are not used for any other purposes besides feeding or mulch to maintain soil moisture. Under such condition higher level of CWP supplementation is recommended. In addition to the prevention of death and weight loss of lambs, higher level of supplementation could bring in addition income from the extra weight gain as observed from this study. If the legume is purchased as supplement to a low quality roughage the effect of substitution rate must be considered. The level of supplementation must therefore be weighed against the amount of the basal feed that will be replaced with increasing supplementation and the differential cost involved. If the cost of the legume is very high then the lowest level of supplementation is recommended which will prevent mortality and maintain a moderate growth rate. The three lambs lost were 50% of the six animals that were fed CS alone. At a purchase price of $17.00 per sheep the total lost was $51.00. At the local and commercial production

level without supplementation, 50% of the total herd represented a substantial loss to the producer.

There were other benefits that are important to livestock producers in SSA which are difficult to quantify. In SSA livestock are produced for religious and ceremonial purposes, a source of traction for plowing and transportation, and they also represent a form of wealth. In Ethiopia and other countries of SSA manure is used as a form of fertilizer, cement for houses, and fuel for cooking. Other factors that were considered were the influence of season on the prices of animals and meat products. Seasonal religious and cultural celebrations are major factors that influence the prices of animals and the demand for meat products (Kebede and Broken, 1990). During festivals (September through December) prices of animals were higher but declined when the celebrations are over. There the level of economic return and profit will varied with time of the year. However, the prevention of death among lambs which resulted in a reduction in economic loss, increased in body weight gain, better incremental returns and value of CWP with supplementation, suggested that CWP feeding CWP was economically beneficial and is highly recommended.

CHAPTER V. SUMMARY AND CONCLUSIONS

In most of SSA, ruminant livestock feed on forages from legumes, grasses, and crop residues. The crop residues which are abundant and commonly used feedstuffs are fibrous, and low in N and minerals. As a result digestibility and degradability in the rumen are low and animals fed these feeds have low productivity. A common challenge facing livestock scientists in SSA is the development of a cost-effective supplementation program that will increase feed intake and digestibility of the crop residues. Establishing an efficient rumen ecosystem, through a strategic supplementation program, which incorporates locally grown nitrogen sources would enhance the utilization of these fibrous feeds. Such a feeding strategy has the potential to increase rumen microbial biomass and as a result improve the overall livestock productivity in the region.

This project was implemented to determine the: 1) nutritional composition, rumen degradation and passage rates of the feeds when CWP and LAB were fed as supplement to CS; 2) efficiency of supplemented rumen environment using ruminal pH, concentrations of NH3-N, VFA, and isoacids, N retained, and microbial N supply as indications of improved nutrient utilization; 3) effects of supplementing CS with graded levels of CWP on intake, digestibility, and metabolism of nutrients; 4) growth performance of Ethiopian Menz lambs fed CS supplemented with graded levels of CWP; and 5) costs and benefits of CWP supplementation.

Results obtained indicated that CWP and LAB contained adequate N and most of the macro and trace minerals needed by sheep. Fiber content (NDF) of CWP and LAB was lower than in CS. Higher lignin concentrations were obtained from CWP and LAB compared to CS. The higher lignin content was typical of legume grown under tropical conditions.

The supplemented rumen environments provided a pH that was adequate for enhancing cellulolytic microbial activity. Concentrations of individual VFA's in rumen fluid were typical for forage fed animals that usually have acetic acid concentrations higher than propionic and butyric acids. There was a significant increase in total and individual VFA concentrations in the rumen of sheep fed supplemented diets as compared with sheep fed CS alone. Isoacids accounted for about 2% of ruminal fluid acids.

Ruminal NH_3-N concentrations in sheep fed graded levels of CWP once or twice daily were higher than in those fed fixed amount of CWP or LAB. Rumen NH_3-N concentrations reached maximum within 1 to 3 h postprandial but declined at the 4th h and remained low for the remainder of the 10 h of observation. Average maximum concentrations ranged from 130.1 to 178.6 mg/l whereas minimum concentrations were 3.6 to 107 mg/l in sheep fed a mixture of CWP and LAB. Maximum NH_3-N concentration in the rumen of lambs fed graded levels of CWP ranged from 250 to 332.4 mg/l and minimum values were 34.1 to 59.7 mg/l. Lowest NH_3-N concentrations were obtained when CS was fed alone. The lower N content and slower degradation rate of N CS compared with CWP and LAB were

probable reasons for the low NH_3-N concentration observed.

There were nonsignificant differences between the rates of DM and N degradation of CWP and LAB, but their rates were higher than the degradation rates of CS. All the feeds reached their maximum DM and N degradation at 96 h of incubation. Percentage DM and N degraded from CS was increased by supplementation which indicated that the rumen environment was improved by feeding CWP and LAB.

Total DM intake was significantly increased by supplementing CS with CWP and LAB. Average CS intake for supplemented and nonsupplemented diets were 519 and 430 g/d, respectively. Substitution of CS with CWP or LAB ranged from 12.6% to 23.6% in Study 1 and 19.7% to 35.1% in Study 2. There were no significant differences ($P>.05$) in total DM, NDF, GE, and N intake between CWP and LAB supplemented diets. Marginal improvement in intake and digestibility of nutrients was observed when CWP and LAB were fed in combination. Lower N content of diets containing the fixed amount of CWP or LAB was suggested to be responsible. Diets containing graded levels of CWP had higher N content, higher NH_3-N concentrations, and hence intake and digestibility of nutrients were improved. Intake and digestibility increased linearly with increased N intake.

The increased nutrient utilization observed from CWP supplemented diets could also be related to the higher degradation rate of CWP compared to CS. A substantial amount (40%) of the DM intake of the supplemented diets consisted of CWP, and its faster rates of degradation could be responsible for the higher intake

and digestibility.

Nitrogen retained and microbial N supply also increased linearly with CWP supplementation. Animal fed supplemented diets had significantly higher values than those from CS diet. The indication was that the amount of N retained was influenced by daily N intake of the sheep. The amount of N retained was also influenced by the fraction of the total N that was bound to fiber. Cowpea and LAB had 8% and 13% ADIN respectively compared with 50% ADIN in CS.

There were significant differences between nonsupplemented and supplemented diets for rates of passage of liquid and particulate matter from the rumen. Rates of digestion of DM and NDF were influenced by supplementation. Mean retention time was reduced by 10 to 15 h with supplementation. Particulate and liquid turnover rates in the rumen and hindgut were significantly higher ($P<.01$) for CWP and LAB compared with CS. Transit time was not significantly ($P>.05$) improved by supplementation.

Results from growth trials in lambs showed significant ($P<.01$) increases in ADG, FCE, and substitution rates of supplemental legumes for CS. Animals supplemented with CWP twice daily had a higher feed intake and reduced CS substitution.

Nonsupplemented lambs lost 17.8 g daily during the 84-day feeding period. Three lambs also died from diets containing CS alone resulting in a financial loss of $68.76. Maximum ADG and total DM intakes were obtained at the highest level of CWP supplementation. Feed conversion efficiency and substitution rates were

similar at CWP supplementation of 267.5 and 397.1 g/d. Financial loss decreased from $68.76 to $13.09 at the lowest level of CWP supplementation. Incremental return from CWP and value of CWP was $55.67 and $4.95 also at the lowest level of CWP supplementation.

The main conclusions from this project are:

1. Cowpea and LAB contained adequate N and most of the macro and trace minerals. Fiber contents (NDF, ADF) were lower, but lignin was higher in CWP and LAB than in CS. The high nutrient content of CWP and LAB indicated that the legumes were potential supplements for low quality forage.

2. Rates of degradation of DM and N from the feeds increased with supplementation. Average degradation rate of 0.06/h was obtained for CWP and LAB compared to about .02/h for CS. About 15% of the DM in CWP and LAB escaped undegraded from the rumen and was apparently digested in the small intestine, whereas 50% of the N in CS was degraded. There was an increase in N retention and microbial N supply with CWP supplementation suggesting that supplementation made sufficient N available for absorption and better performance of lambs compared with feeding CS alone.

3. Ruminal pH, concentrations of NH_3-N and VFA, N retention, and microbial N supply were increased could have been responsible for an increased intake and digestion of feeds for CWP and LAB supplemented diets. Twice daily supplementation maintained a higher NH_3-N concentrations for a longer time, resulting in higher feed intake, and greater ADG was higher at the end of the 84-

day feeding period.

4. Growth rate was improved by feeding graded levels of CWP. Maximum ADG was obtained at the highest level of CWP supplementation. Supplementation of CS was profitable at all level of CWP feeding compared with a substantial loss from nonsupplemented lambs. In addition to the prevention of mortality and weight loss there were increase in profit, net return from CWP and a profit of $1.69 at he highest level of CWP supplementation. There were many other social benefits of livestock that this study did not address. Results from the experiments on the effects of using forage legumes as supplements to CS on nutrient utilization, growth rate, and economics of supplementation suggested that CWP supplementation is highly recommended even at the lowest level. The prevention of death of animals and the maintenance of a moderate weight gain are benefits that are very important to many farmers during period of limited feed supply.

Results on nutrient compositions, rate of degradation and passage of feeds from the rumen, improvement in rumen metabolites, and the subsequent improvement in feed utilization and growth performance indicated that CWP and LAB are potential supplements for ruminants consuming diets composed of low quality roughage such as CS.

Future studies should assess the availability of the minerals found in CWP and LAB. There is also the need to quantify the density and type of microbial population created by supplementing CS with CWP or LAB. Investigations to evaluate the availability of the minerals found in CWP and LAB would indicate

whether mineral block supplementation is necessary, a feed ingredient that might not be available most of the time to local farmers. Quantifying the microbial population will give an indication of the efficiency of the rumen environment created by supplementation. Finally economics of supplementation research must be done at an interdisciplinary level including social scientist and animal nutritionists. An on-farm trial compared with on-station study would give a better insight into the socio-economic impact of forage legumes supplementation.

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